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APPROACHES TO DEALING WITH MOTOR VEHICLE AIR
POLLUTION: REPORT OF THE SUBPANEL TRANSPORTATION
SYSTEM REQUIREMENTS OF THE PANEL ON ELECTRICALLY
POWERED VEHICLES

Edward H. Blum

The Rand Corporation
Santa Monica, California

December 1967

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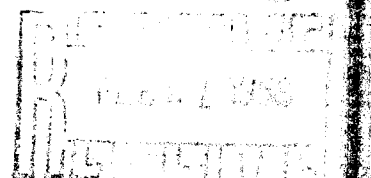
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Report of the Subpanel on Transportation System Requirements of
the Panel on Electrically Powered Vehicles.

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The report that follows was written as one of six subpanel reports comprising background and support for the report of the Panel on Electrically Powered Vehicles. ** It appeared originally as part of "The Automobile and Air Pollution: A Program for Progress--Part II," published in December 1967 by the U. S. Government Printing Office.

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**The Panel on Electrically Powered Vehicles was appointed in January 1967 as a study group under the Commerce Technical Advisory Board by the Secretary of Commerce, in a joint sponsorship agreement with the Departments of Defense; Health, Education and Welfare; Housing and Urban Development; Interior; Post Office; and Transportation; the Atomic Energy Commission and the Federal Power Commission. Despite its name, the Panel was convened for the broad task of finding and recommending suitable means of reducing motor vehicle air pollution. Its charter included but was not restricted to electric vehicles. More specifically, the Panel was charged to survey, evaluate, and compare alternative means of reducing vehicular air pollution, and to recommend appropriate roles for the Federal Government.

The report of the Panel, entitled "The Automobile and Air Pollution: A Program for Progress--Part I," was published by the U. S. Government Printing Office in October 1967. The subpanel reports were collectively published in the volume from which this report was reprinted. The five other subpanel reports, which complement this one, cover Air Pollution, Current Automotive Systems, Energy Storage and Conversion Systems, The Automobile and the Economy, and Automotive Energy Sources.

The report is reprinted here directly from the original collective volume, retaining that volume's pagination and including its entire bibliography. It has been reprinted for three main reasons. First, it appears to be of interest to an audience that may not be reached by the original volume. Second, although not a formal product of RAND research, it represents RAND's growing concern and involvement with domestic, social problems. Third, although definitely not a systems analysis, it appears to offer a useful example of how a systematic approach may help structure -- and perhaps clarify -- a complex public issue.

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TRANSPORTATION SYSTEM REQUIREMENTS

SUBPANEL ON TRANSPORTATION SYSTEM REQUIREMENTS

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INTRODUCTION AND OVERVIEW

"When the time is run, and the future become history, it will be clear how little of it we today fore-saw or could foresee. How then can we preserve hope and sensitiveness which could enable us to take advantage of all that it has in store? Our problem is not only to face the somber and the grim elements of the future, but to keep them from obscuring it. . . ."

"[The means] of doing justice to the implicit, the imponderable, and the unknown, . . . is sometimes called style. It is style which makes it possible to act effectively, but not absolutely; it is style which . . . enables us to find a harmony between the pursuit of ends essential to us and the regard for the views, the sensibilities, the aspirations of those to whom the

problem may appear in another light; it is style which is the deference that action pays to uncertainty; it is, above all, style through which power defers to reason."

—J. R. Oppenheimer

Purpose of the Report

The purpose of this Subpanel report is to develop—in the sense of the above quotation—a style for vehicular pollution policy. The Subpanel has chosen as its task complementing the other subpanels—i.e., treating aspects of vehicular pollution not directly concerned with specific technology and constructing a systematic framework within which the vehicular pollution problem can be seen and analyzed as a whole.

If parts of the report seem abstract, they are deliberately so. We have sought to free many ideas from the anchors of current information. We have attempted to generalize where possible in the hope of discovering or illuminating principles that will outlast the context from which they were derived. Much of the rest of this Panel report will be obsolete in a decade; the nature of technical information makes that inevitable. We hope that this Subpanel report will, perhaps, contain ideas and information with longer half-lives.

In one sense, this report is designed to serve as a first step in a thorough systematic analysis. It is aimed at bringing the implicit and unknown out into the glare of scrutiny. Within its limited scope, of course, a detailed comparison of alternative policies cannot even be begun. Such comparison must await future efforts based on more extensive and more complete information. Rather, here we attempt to form a basis for action and sound progress—to develop a way of looking at vehicular pollution that may help shape attitudes, increase sensitivities, and guide policies now, and serve as a basis for detailed investigation in the future. We hope also to stimulate thinking and research on the many questions raised here that cannot now be answered.

Overview

The Subpanel report contains five sections (in addition to this one) and a three-part appendix. The first section discusses briefly the nature of pollution control objectives. The next section, somewhat longer, discusses the structure and character of pollution control analysis. It reviews some of the problems encountered in policy analysis and describes the structure of systematic analysis that is followed in the remaining sections.

The third section then develops evaluation criteria. It examines policy constraints, criteria for pollution control and costs, and criteria imposed by administrative and economic considerations. Two quantitative models (developed in appendices 1 and 2) are presented to tie together aspects of pollution control.

The fourth section presents a broad spectrum of alternatives, and draws upon the criteria for evaluation. It also examines possible impacts of pollution control policies on the national economy and on the disadvantaged and poor.

The fifth section discusses uncertainties. It examines their policy implications, outlines some areas for research, and suggests approaches to system experimentation.

POLICY OBJECTIVES

This section examines the bases and objectives for vehicular pollution control. Its purpose is to explicate the nature of the policy problem and to set the stage for the more detailed chapters that follow. The section is divided into two parts, which cover (1) differences between private and collective views and (2) objectives for vehicular pollution control.

Differences Between Private and Collective Views

It might be said, with regard to policy, that vehicular air pollution arises mainly because of discrepancies between private and collective points of view. It is well known that unwanted effects* such as air pollution may arise whenever market forces alone are insufficient to make individuals bear all the costs resulting from their actions. Without control policies, the air is used as if there were no costs from pollution, and air pollution tends to rise to levels considered socially undesirable.

What has not been made clear in the literature is that the problem is really even worse. There is not only no incentive for individuals not to pollute, but there are actually forces discouraging the adoption of controls. This situation arises because

(a) At low levels of control, each individual sees the cost of control, but sees no benefits. Each one says to himself, "This action costs me money, but what do I gain unless everyone else does it too?" Unless some mechanism for encouraging or forcing cooperation is set up, individuals tend to view money spent on pollution control strictly as cost. If an individual does not spend the money, then insofar as he can determine, pollution does not get worse. If he does, then also insofar as he can determine, it gets no better. Thus, he has little reason to adopt pollution controls. In this sense, the vehicular pollution problem has elements in common with the problems of traffic congestion and farm surplus (where there are similar discrepancies between individual and collective viewpoints), and is one of a class of problems known in philosophy and mathematics as the "prisoners' dilemma."

(b) At high levels of control, each individual sees little gain from continuing his pollution control, and little loss from stopping it. Air is an indivisible resource, a quantity like defense and law and order that cannot be denied to those who do not pay for it. Thus each person shares in the benefits of pollution control whether he contributes to it or not. Those who do not wish to contribute have the chance, then,

*In economics these effects are termed "external diseconomies."

to get a "free ride" by halting their spending on control. As long as everyone else does not do the same, they get the benefits of cleaner air without direct cost. Policy then has the job of ensuring that there are not many free rides, for if there are too many, the system will break down, and pollution control will be lost.

Pollution control policy thus must counterbalance a basically unstable situation. No matter which direction pollution control moves from a given level, the discrepancies between private and collective views may lead to slackening or dropping of individual control efforts. If general control improves, some people may seek free rides. If general control worsens, some may decide not to bother.

The solution to this dilemma is to ensure that the collective view predominates. For vehicular pollution this solution is somewhat easier to achieve—in one respect—than it is for industrial pollution, because to a substantial degree polluters are imposing costs (or "externalities") reciprocally on each other. It is therefore easier to make clear to each vehicle driver that he may gain if he stops polluting, whereas in industrial pollution it is not always clear what any one company can gain from reducing its effluent. The solution is, on the other hand, also harder to achieve than that for industrial pollution because the number of vehicular polluters that must be brought into the collective view is extremely large.

Objectives For Vehicular Pollution Control

Vehicular air pollution is one of the undesirable by-products of operating the transportation system. It is produced concomitantly with the desirable services that the system performs. A consideration in vehicular pollution control policy, therefore, is maintaining, improving, or at least not seriously degrading the desirable features of the transportation system while minimizing pollution. More formally, one might say that reducing desirable attributes of the transportation system would result in social costs which would have to be weighed against the benefits of reducing air pollution.

Pollution control policy, thus, must not be guided solely by the objective of eliminating pollution. If that objective were to be interpreted literally, it would imply that the best policy would be to forbid use of the internal combustion engine or of any other engine that produced emissions. Pollution control policy has multiple objectives which it must attempt to satisfy as best it can.

If costs of pollution and the benefits to be gained

by its reduction could all be reduced to simple monetary terms, then one might hope to formulate as a policy objective: maximize the net of benefits minus costs, subject to the constraints. Many of the so-called costs of pollution, however, are "humane" costs that do not easily lend themselves to monetary valuation.² The esthetic discomforts caused by pollution, the continual irritation, the loss of work efficiency may be reflected in expenditures for comfort, pleasure, and freedom from discomfort, but are not totally measured by them. Some of the "humane" costs are detractions from what "makes life worth living." The costs are subtle, subjective, and not always even well articulated. They reflect basic values, and not every value has a price.

Thus, as the sections on Structure and Character of Analysis and Criteria show in much more detail, there is no one simple statement of objectives for pollution control that satisfies the diverse ends any control policy must meet. There is no one simple index that can be optimized. Policy must take into account a very large and complex set of considerations. It is bounded by many constraints and governed by dozens of criteria. Only one simple statement of objectives is likely to gain wide agreement. That is, simply, "Do better."

STRUCTURE AND CHARACTER OF ANALYSIS

The purpose of this section is two-fold: to develop the character and structure underlying the more specific analysis in later sections of this report and to establish a basic framework and perspective that might be useful in future analyses of the vehicular pollution problem.

In this section we (1) examine features of the problem that make analysis difficult; (2) point out some of the pitfalls these features can lead to in analysis; and (3) describe a method of systematic analysis that may take these difficulties into account. The systematic structure and approach developed in this section is then used in the remainder of the report to guide the analysis and to indicate areas where synthesis (i.e., new ideas for solution) might be especially fruitful.

Features That Make Analysis Difficult

The problem or problems resulting from motor vehicle air pollution can be viewed in a number of

²The judgement that all things can be reduced to economic terms represents a definite (and not widely shared) set of values.

ways. A popular view, for example, is that the problem is basically too many cars, trucks, and buses emitting too much exhaust in too small an area, and that the solution, therefore, must be either (a) fewer polluting vehicles (e.g., substituted mass transportation or electric vehicles), (b) less exhaust per vehicle (e.g., emission controls on the internal combustion engine), (c) fewer vehicles in the same area at the same time (e.g., traffic restrictions), or (d) some combination of these. There is much to commend in this characterization—especially its brevity—but, as the preceding subpanel reports have shown, the problem has many more dimensions and is a good deal more complicated.

Unfortunately for the analyst and the formulator of policy, acknowledging this complexity and attempting to deal with it open a Pandora's box of analytical problems. It would be easiest to adopt the simplest view, assume that the current line of action—pursued to the point where it exhausts its political credit—is the best course, and focus full attention on the means of completing that course most quickly. Yet, because vehicular air pollution is a serious problem, and it is not clear that the current program of action will be able to solve it, on a problem this important the public deserves a more searching and extensive view.

Analysis is more difficult than the above description suggests essentially because motor vehicle air pollution and its proposed remedies:

- (a) involve both people and technology, and the complex interactions between them
- (b) affect large numbers of people directly, in multiple (and often unknown) ways
- (c) entail costs to consumers that, in aggregate, may be quite large
- (d) involve technology for which performance and economics are still quite uncertain
- (e) have important implications for the future as well as for the present.

To see how these characteristics are important, it is useful first to bring into perspective the nature of the motor vehicle air pollution problem.

Nature of the Problem

Vehicular air pollution is only one element of the total complex of urban problems. To place it in context, therefore, and to see relations between various contributing factors, it may be useful to examine the following simplified chain of events:

- (a) Metropolitan form (e.g., the spatial relationship of homes to jobs, and to shopping, recreational

and cultural facilities), income levels, and the characteristics of the transportation system strongly influence the over-all

- (b) Demand for transportation, of which part is

(c) Demand for motor vehicle transportation (automobiles, trucks, buses). This demand can be divided into commercial and individual components which have different determinants. The detailed demand results in a flow which is manifested as a

(d) Distribution of vehicle-miles and speeds driven in particular areas. The distribution of speeds and distances driven determines, to a large extent, the motor vehicle power that must be produced.

(e) To supply power, fuel is supplied to vehicles. Part of the fuel evaporates (mainly from the carburetor and the gas-tank) without being burned, and goes directly into the atmosphere. The rest goes into the engine where the

(f) Over-all performance of the engine-fuel system determines the amounts emitted as carbon dioxide, water, carbon monoxide, nitrogen oxides, lead compounds, unburned hydrocarbons, reacted hydrocarbons, sulfur oxides, and miscellaneous other substances. These emissions go into

(g) The atmosphere immediately surrounding the vehicle, where very local atmospheric conditions determine the immediate disposition of the pollutants. Local convection and diffusion merge the emissions into

(h) The local atmosphere, where micro-meteorological conditions (what might be termed small-scale weather) determine the local pollutant concentrations. At this point drivers and people living or working very near the street or highway may be exposed to pollutants in high concentrations. From the local atmosphere, larger scale convection (and some diffusion) carries the pollutants into the

(i) Regional atmosphere, where the pollutants may contribute to area-wide haze, or on exposure to intense sunlight (often aided by atmospheric inversions) form photochemical smog. If the region includes a city, convection cells around the city (arising from the temperature differences between the city and surrounding countryside) may give rise to "dust domes" that contain pollutants and alter the local climate.¹² Beyond the region, larger-scale atmospheric motions carry pollutants into the

(j) General atmosphere, where they may influence large-scale weather patterns and be dispersed around the country and around the world.

The steps in this chain of events thus can be summarized as: Social and Economic—Technological

Meteorological. All steps in the chain from (a) through (h) are important in creating the vehicular pollution problem.

Once created, vehicular air pollution has the following characteristics:

- It contaminates a precious, slowly regenerated resource with substances that are offensive and harmful to human beings and harmful to some of their agriculture and property.
- It affects individual members of the public directly, by hindering their vision, assaulting their sensitive tissues and sense of smell, and by affecting (often implicitly) property values in areas where pollution is severe.
- The contaminated fluid is highly mobile and thus can, often unpredictably, affect areas remote from the original sources.
- The degree of contamination and the severity of its effects vary considerably with meteorological conditions, both spatially and from hour to hour. Because air is mobile and pollution effects depend on immediate local weather, even areas that have no noticeable problems may have serious latent problems if sufficient sources exist.
- The continuing sources of contamination are widely distributed, mobile, and (for the most part) owned and operated by individuals. Individual actions and choices contribute directly to the problem and are affected directly by attempts to solve it.

Social-Technical Interactions

Motor vehicle air pollution thus results, as a serious problem, not from technology alone but from an intimate interaction between social and economic factors, technology, and meteorology. Its solution is at least as complex. It may appear easiest (and possibly most fruitful) to concentrate on purely technological solutions—what Alvin Weinberg¹² has called the “technological fix”—because technology is more susceptible to quick and controllable change than social and economic factors or meteorology. But, because of the nature of the problem, the amenability of technology is largely relative; technological changes must interact closely with social and economic considerations.

New transportation technology (i.e., mass transportation, electric or steam vehicles, or pollution-control applied to the internal combustion engine) affects directly individual members of the public, who must as individuals pay for it, use and live with it, maintain it (in the case of individual vehicles), suffer from its defects, and only indirectly share in its pol-

lution-control benefits. Furthermore, these individuals must continue to support application of the technology through their legislative representatives, who must approve its requirement and appropriate money for pollution-control administration.

Pollution-control technology is thus subject to evaluation by social and economic criteria, and subject to limitation by complex social and institutional constraints. Moreover, where technological possibilities, performance, costs or development time are uncertain, the uncertainties must be interpreted in light of their possible social and economic implications. Yet these social criteria, constraints, and implications that influence technological development are themselves influenced by the characteristics of the technological alternatives that the public and governmental decision-makers perceive to be available.

Between technological and social considerations there thus is a closed loop, wherein each feeds back to influence the other. In analyzing possible solutions to the motor vehicle pollution problem, technical and social considerations cannot be divorced. Conclusions derived from considering only one or the other, or both separately, are likely to be misleading, if not erroneous. First, the assumptions and values inherent in purely technical and social analyses are quite different, indeed often conflicting, and rarely explicitly stated. Thus, meshing the results of separate technical and social considerations without dealing with the interactions is likely to lead to plans and policies beset by internal contradictions and inconsistencies.⁹

⁹“... technical package consisting of many components may be (and often is) assembled and ‘optimized’ according to criteria quite incompatible with those desired socially or politically—e.g., minimum short-term direct cost (ignoring benefits, long-term costs, and indirect ‘social’ costs), technical efficiency (related usually to one scarce input, ignoring all other scarce inputs and the costs and benefits of outputs), maximum production, etc. Even if the criteria are explicitly stated, which they often are not, they are so different from the criteria used ordinarily [for social judgment] (equitability, benefits to special groups, scope for individual initiative, etc.) and use such different scales that reconciling discrepancies is extremely difficult.

First, it is often hard to recognize where conflicts exist, because the criteria are expressed in different terms which refer to different value systems. Second, since the technical and social alternatives are usually offered as complete packages, within which compromises and trade-offs have been made according to the respective (different) criteria, it is difficult to extract from the total packages parts compatible with over-all criteria. Even if one can dissect the different packages to obtain compatible parts, one has no assurance that the parts will function well together as a system.” (Quoted from Ref. 25).

Such products may satisfy neither the technical nor the social objectives, and may be quite undesirable.

Second, and perhaps even more basic, considering technical and social aspects separately is likely to prevent proper definition of the real problem to be solved. Those who evaluate non-technological aspects of the problem often are inclined to accept the statement of the technical problem, and the "feasible" solutions, as given. Similarly, engineers are inclined to regard the statement of the non-technical part of the problem also as given, and hence exempt from questioning or reformulation. Thus, the most important parts of the problem statement may fall between them, accepted by both without questioning as the other's concern.²⁵

Individual Effects and Costs

The main effects of vehicular air pollution on individuals can be categorized as **discomfort** (e.g., physical discomfort, depression, dissatisfaction with unpleasant aesthetic and biological effects), **medical** (e.g., possible effects of carbon monoxide, oxidants, hydrocarbons, lead, etc.), and **economic** (e.g., damage to property and crops, work lost and or costs incurred through illness or condition aggravated by pollution, decreased work efficiency due to discomfort).

The discomfort effects of vehicular pollution are difficult to evaluate mainly because they are strongly associated with those resulting from other aspects of urban living—especially, one might surmise, with those resulting from other forms of air pollution. Not only is it hard for most people (except, perhaps, in Los Angeles) to isolate the features of their discomfort and dissatisfaction that might be attributable to vehicular pollution, but given our present state of knowledge, it is also extremely difficult for doctors and scientists to single out what vehicular pollution contributes to the general causes of distress. Discomfort effects, in general, are very probably compounded and non-additive.

Even if it were possible to single out the discomfort effects of vehicular pollution, it would still be difficult to assign values to them. The discomfort effects are clearly significant; people attach considerable importance to comfort and satisfaction (as almost any collection of current advertisements will attest). The problem is determining how important they are, and how much they may change as vehicular pollution levels are reduced. In theory, at least, such measurable indices as residential property values, frequencies of pollution-escaping weekend

trips, and sales of "comfort" medicine might serve as proxies, but these are so strongly associated with many other factors that even reliable correlations with vehicular pollution may be difficult to obtain.

Chronic medical effects also pose some difficult measurement problems. For some pollutants—e.g., lead—baseline data from the years before the pollutant was introduced in significant amounts are insufficient to permit the analysis of long-term trends. For others, not enough data for selected populations over a long period of time have yet been collected. For still others, it has not been established just what chronic effects should be measured, or how much of the effects that have been measured can be attributed to vehicular pollution. As the report of the Subpanel on Air Pollution shows, knowledge of acute effects is more complete, but interpretations are not yet well agreed upon.

Careful evaluation of economic effects has just begun, and many serious methodological problems remain.*

For pollution control, some of the individual effects and costs of pollution control modifications and fuel changes for the internal combustion engine should be clear, as should (at least statistically) the costs of maintaining the pollution-control changes, and the benefits from reduced fuel consumption. The effects of changed motor vehicle performance characteristics—or of the different characteristics of electric or steam vehicles, should they be introduced in significant numbers—will be less simple to determine. Even more difficult may be determining the effects and costs of the re-allocation and redistribution of resources ensuing from pollution-control regulation. There may be noticeable effects on the economy and, perhaps, on certain groups such as the poor.

Since more than 80 million vehicles ultimately will be affected by pollution control measures, the aggregate amount of resources involved in pollution control will be large. If the costs were to be \$15 per

*See, for example, R. G. Ridker, *Economic Costs of Air Pollution: Studies in Measurement*, Frederick A. Praeger, New York, 1967.

R. G. Ridker and J. A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics*, 49, 246-257 (1967).

H. Wozolin (Ed.), *The Economics of Air Pollution*, W. W. Norton, New York, 1966.

The Ridker book and paper do not deal with vehicular pollution, but the analytical methods and problems are not pollutant-specific. The papers in the Wozolin collection are more general, but illustrative.

vehicle in present value, for example, the aggregate amount involved would exceed \$1 billion. And, as the Subpanel on the Automobile and the Economy has shown, the total output affected by the changes (though in some cases perhaps only slightly) represents a sizeable share of the Gross National Product. Thus, the economic implications of alternative approaches deserve close scrutiny. Yet rather than good information on the costs involved, we now have but broad indications.

Technological Uncertainties

The ultimate limits of internal combustion pollution control are not now known; nor are the cost and time required to achieve them. And it is not known whether these ultimate limits, if achieved, would be truly satisfactory. Although internal combustion pollution control is likely to prove the best short-term (i.e., 1-15 years) technological approach, it may not be good enough for the long term. As the report of the Subpanel on Current Automotive Systems shows, there is still considerable uncertainty about the degree to which specific pollutants can be controlled, and about the tradeoffs that may have to be made—e.g., between lead and catalysts, between fuels and engine design, between hydrocarbons and oxides of nitrogen. It is not known with certainty what technology will be needed to achieve emission levels below those currently envisioned, nor is it known what the cost-time relations for research and development might be. It is also uncertain how various pollution-control modifications might affect motor vehicle operating economy and performance.

With regard to new kinds of vehicles (e.g., steam or electric) many basic technical problems remain to be solved, and there remain many serious questions about performance and costs—as the report of the Subpanel on Energy Storage and Conversion Systems shows. In some areas, even relatively basic scientific research may need to be done, so that it will be difficult to make even enlightened conjectures about possible technological characteristics.

Moreover, there are uncertainties about the implications of some possible changes for other aspects of the general pollution problem: Air pollution is, of course, only one of the undesirable products of the transportation system. Changes directed at reducing air pollution can also affect the system's other products. If vehicle bodies were to be made of plastic to reduce weight and improve performance, for example, they might eventually be cheaper and easier to produce than metal bodies, but harder to dispose of

when the vehicle had outlived its usefulness, unless scrap plastic could be found to have some value or be easily disposable.

Implications for the Future

Resolving major uncertainties—such as those concerning chronic medical effects, feasibilities of advanced technology, public acceptability of changes in transportation (e.g., engines to use lower-octane unleaded gasoline, electric vehicles, dual-mode systems), and economic redistribution effects—may take a long time. Until these uncertainties are satisfactorily resolved, or rendered irrelevant by advances now unforeseen, there is always a possibility of significant "hidden effects" that may be discovered and understood only after they have resulted in significant harm. Thus, analysis (and subsequent policy) must attempt to take into account possible risks.

Moreover, some of the changes introduced for pollution control may have long-lived effects, not all of which may be beneficial. We must try to be certain we do not replace one serious problem with another.

There is also a problem of designing evolutionary strategies to take account of increasing knowledge. Permissible radiation-exposure levels, for example, have decreased steadily since 1945 as more knowledge of radiation effects has accumulated. If permissible pollutant levels were similarly to decrease over twenty years, long-term development now being planned might yield products that become obsolete just as they become "successful." Analysis cannot assume, therefore, a fixed level of permissible pollution or even a fixed program of reduction. Learning must be accounted for—in objectives, in analysis, and in policies.

Further, it is apparent that decisions made now may both restrict and expand opportunities available in the future. Present commitments may limit future options; thus, "preservation of future freedom of choice" may need to be an important criterion for evaluating major commitments. Similarly, current programs may need to be laying better foundations for the future by acquiring information, monitoring projections, and conducting important experiments. Analysis cannot afford to focus entirely on the present.

⁴Such unplanned obsolescence, though often met in the space and defense industries, appears to have been rare in the ground transportation industries. New management approaches and perspectives may be needed to handle such problems in efforts not heavily underwritten by the Federal government.

Problems and Pitfalls

In theory, "it is easy to state the principle by which the socially desirable amount of pollution abatement should be determined: **Any given pollution level should be reached by the least costly combination of means available; the level of pollution should be achieved at which the cost of a further reduction would exceed the benefits.**"^{*} In practice, such a principle is exceedingly difficult to implement. Given the current state of understanding, it would be difficult to ascertain or measure all benefits and costs—or even all major ones—and more difficult to assign a common (dollar) denominator to many of them. Many of the benefits and costs are not only intangible but (such as air pollution's aesthetic offense) highly subjective and weighted by different people in different ways. And many sub-objectives and criteria now espoused are conflicting and incompatible, no doubt to some degree because interactions between transportation technology and social environment are now dimly understood.

Furthermore, even if these formal difficulties could be overcome, it would be—as in most social problems—not profitable to search for an optimal solution. First, an optimum is ill-defined when there is more than one criterion. Second, a formally optimal set of conditions (if such existed or could be determined) would very likely differ significantly from current conditions, and reaching the optimum might well entail significant, albeit temporary, social dislocation. Such a wrenching move, which would affect at least some individuals directly, might well cause many who now deplore current conditions to value the status quo simply because it is the status quo and hence at least tolerable and familiar.^{**}

Faced with such problems, analysts examining possible changes in transportation technologies frequently are inclined to^{***}

(a) Concentrate heavily on the vehicle rather than upon the organic functions of the system.

(b) Neglect, and sometimes disregard, the social

and human consequences of modifications or new creations.

(c) Favor "interesting" transport technologies whose social significance may be (or probably is) inversely proportional to their cost.

(d) Disregard the cost implications of an innovation and of the economic environment in which it will have to operate. What will be the development cost of the vehicle and, more important, of the system that must be built around it? What price will people be willing to pay for the service it provides? With what improved present forms of transport will the new system have to compete by the time it goes into operation?

(e) Ignore the extraordinarily long gestation period often required for carrying development programs to completion.

(f) Accept people's current objectives and values as given and try to build a transportation system to match them. Almost certainly the goals will be changed by the process of growth and by the very transportation path that will be followed.

In addition, analysts are often tempted to:

(g) Overspecify the requirements for new technologies, without knowing well either the time or expense that will be needed to meet the requirements or the real need for the requirements in the future context.

(h) Ignore the implications of troublesome uncertainties, and advocate only the one system that promises to be best under some set of expected conditions, or

(i) Assume that the worst will happen, and advocate the technology or system that promises to be best under the worst possible conditions, ignoring the likelihood that this worst possible contingency will ever arise.

Systematic Analysis

To overcome these inclinations and temptations, it is useful to follow a systematic analytical outline or framework. Such a framework offers a logical structure or a "guiding hand" for the solution of complex social-technical problems, much as the scientific method does for scientific problems. There are obviously many variations on the basic theme of systematic analysis, just as there are for the scientific method; we have found the following structure useful:

(a) Define and resolve problems according to the various levels of importance, focussing primary at-

^{*}Reference, 323, p. 42.

^{**}Americans have shown great willingness to forgo and sacrifice in face of great need or danger. But motor vehicle air pollution, though acknowledged as a vital problem requiring prompt attention, has not been acknowledged as the kind of crisis whose solution would be worth enduring even temporary significant discomfort without visible concomitant benefits. (See, for example, the results of the Louis Harris survey reported July 24, 1967, in the *New York Post*—and briefly mentioned July 26, 1967, in the *New York Times*.)

^{***}H. Heymann, Jr., *Transportation Technology and the Real World*, The RAND Corporation, P-2755 (June 1963).



tention on the most important levels, and using consistent inter-level objectives and criteria.

(b) Explicitly identify objectives, criteria, assumptions, uncertainties. Consider the policy implications of criteria and possible impacts of uncertainties. Iteratively formulate and reformulate objectives and criteria as analysis proceeds.

(c) Explicitly account for interactions and "spill-over" between subsystems. Explicitly account for the interactions between technical (i.e., engineering) and social considerations.

(d) Consciously seek alternatives. Devise new alternatives when necessary or desirable. Compare a graded spectrum of alternatives rather than just analyze one.

(e) Explicitly and systematically compare alternatives for consequences and, where possible, costs and benefits. Explicitly identify critical or sensitive points that demand special policy attention.

Using this framework and drawing on the relevant literature of systems analysis* are useful in detail as well as in general. The literature, for example, calls

*No comprehensive, readily accessible reference on non-military systems analysis seems yet available. Two books on military systems analysis that contain informative and relevant chapters are

E. S. Quade (Ed.), *Analysis for Military Decisions*, Rand McNally & Co., Chicago, 1964.

E. S. Quade and W. I. Boucher (Eds.), *Systems Analysis and Policy Planning: Applications in Defense*, Elsevier (to be published).

attention to the fallacy of setting the oft-cited goal of maximum benefits at minimum cost. Given measures of benefit and cost, which must include both technological measures and indicators of indirect and social value,** one can look for a system that gives (of the available alternatives) maximum benefit at a given level of cost, or a given level of benefit at a minimum cost. But maximizing benefit while simultaneously minimizing cost is logically impossible (as a general rule).

From the literature, it is apparent also that some discounting factor must be applied when comparing benefits (e.g., reduced fuel consumption, reduced pollution) yielded at different times. Just as a dollar earned today is worth more than a dollar earned some years hence, because of the interest that can be gained in the intervening years, so reduced pollution today is worth more than the same reduced pollution some years hence, because of the benefits that can be gained from the cleaner air in the intervening years.

Further, experience with military systems analysis underlines the importance of accounting for both risk and uncertainty in devising long-range policies. Risks, as in the case of individual fortune, can usually be met best by some form of insurance or diversification. In risky or uncertain situations setting a single, fixed course and pursuing it intensively may not be as fruitful as following a more flexible strategy that permits learning from experience and takes positive steps to account for risks or uncertainty. It has been found, for example, that in the face of uncertainty some fruitful strategies often are

(a) To follow a course of action that will have "acceptable" probabilities of success under wide varieties of possible conditions; that is, to choose "safe" actions that are likely to have positive effects "no matter what."

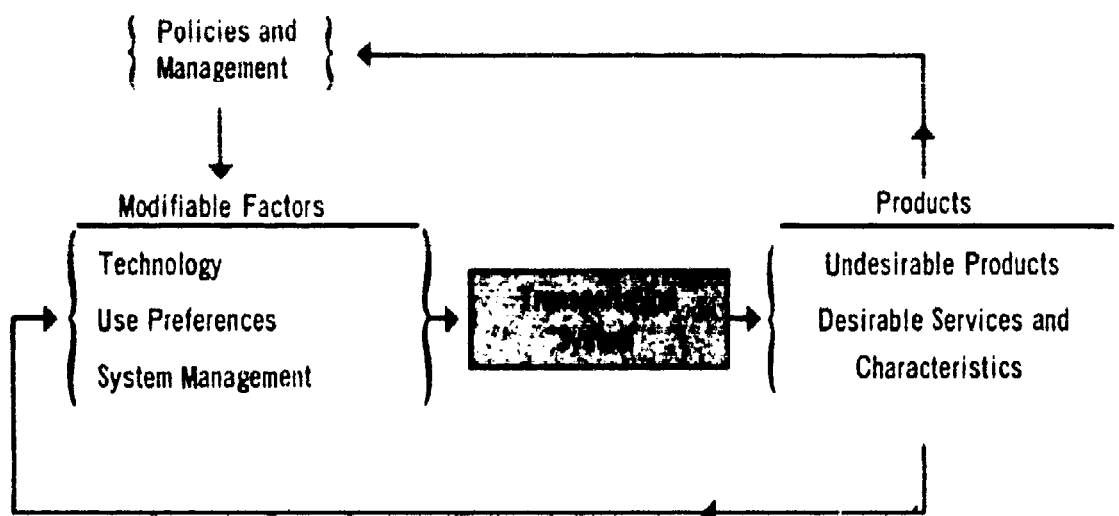
(b) To launch a multi-pronged attack, with some effort directed at solving current and short-range problems, and other efforts directed toward learning what may be needed for effective long-term solutions. These efforts are usually carried out in parallel, with the longer-term effort conducted so as to preserve as much freedom as possible to choose and change direction.

Within the framework of systematic analysis, the

**The measures of costs must include indirect and social costs as well as conspicuous out-of-pocket costs. Otherwise the "least cost" course is to do nothing at all. Air pollution is a serious problem because it leads to significant private and social costs.

transportation system can be viewed as follows:

FIGURE 34



Policies and management work on the modifiable factors to change the transportation system's operations and properties, and thereby to change the system's products. Since the changes may only partially reduce the undesirable products (e.g., pollution) and may affect desirable as well as undesirable features, information on the new state of the products is fed back to influence future policies and management. Similarly, those who use the transportation system also observe the changed products and adjust their use preferences accordingly.

Alternative policies can be generated in a number of ways. One fruitful way is to consider the interaction of the modifiable factors with the air pollution chain of events. (See page 330). The modifiable factors are

- Technology** —e.g., vehicle engine-fuel systems, roadway design, means of cleansing the atmosphere.
- Use Preferences** —e.g., relative locations of homes and jobs, demand for less polluting modes of transport, driving and maintenance patterns.
- System Management**—e.g., traffic flow and assignment, pricing, parking availability, public regulation.

At each of the key points in the air pollution chain, modifying one or a combination of the factors provides leverage to deal with vehicular pollution.

Cross-classifying modifiable factors and the chain of events thus would be one way of showing graphically the approaches through which motor vehicle air pollution may be attacked. Since only a few of these potentially vulnerable points are now seriously being attacked, such a cross-classification would also serve to show where new work might be fruitful. By laying bare the central structure of the motor vehicle air pollution problem, it could suggest new activities and new approaches. That is, it could serve as a framework for synthesis and a focus for innovation.

Most public attention has been directed toward technology, i.e., toward modifying or changing the automobile engine, and some has been pre-occupied with gadgetry. Engine change or modification is likely to be one of the most effective approaches (at a given level of cost). But it is not the only approach. Despite the relative difficulty of carrying them out, non-technological approaches (i.e., modifying use preferences and system management) also may be effective.* If pursued in parallel with technological

*Technological approaches, being easier, more straightforward, and less likely to produce major side-effects, should be tried first. Non-technological approaches would be unnecessary if technology alone would suffice.

approaches, they may help achieve pollution control while the technology is still being developed and increase the effectiveness of the technical approaches that are adopted.

Indeed, a combination of approaches—of different changes in technology and of changes in use preference and system management—is likely to prove superior to any one approach alone. Several of the approaches might well complement and reinforce each other, producing a synergistic effect exceeding the effect any one alone could yield. A combination of approaches also appears needed to deal effectively with technological uncertainty and the vagaries of research and development. There is not likely to be one "solution" to motor vehicle air pollution.

The sections that follow begin to fill in details of systematic analysis. The section labelled **CRITERIA** explicitly identifies criteria and constraints, and considers their implications. The section labelled **ALTERNATIVES** develops a broad spectrum of alternatives, considers interactions, and uses the criteria to indicate very approximate evaluations or rankings. The section labelled **UNCERTAINTIES** examines uncertainties, and explores their possible impacts and their implications for policy.

CRITERIA

This section identifies criteria and constraints, and considers their implications. Its purpose is to make explicit the standards that should guide the design of alternative approaches to vehicular pollution and form the bases for their comparison.

The section has six parts, which cover (1) the role of public values, (2) constraints, (3) criteria for pollution reduction and costs, (4) criteria for effects on the motor vehicle system, (5) administrative and economic criteria, and (6) criteria for the Federal role.

Role of Public Values

By its very nature, vehicular air pollution is a public problem whose proposed solutions must be judged by more than the private standards of profit and loss. The criteria for evaluating proposed solutions transcend simply pollution reduction and net cost. They also involve, for example, special impacts on particular parts of the population, effects on the motor vehicle (transportation) system, risks to public welfare, and administrative complexity. Although some of these criteria are amenable to quantification, others are not. Thus, the scales for rating alternatives

are in part numerical, in part preference rankings, and in part simply checklists of possible ill-effects.

Because of the problem's complexity and ramifications, no simple rule for choosing the "best" alternative from the set of possibilities—such as "subject to the constraints, maximize the net of benefits minus costs"—appears to be meaningful. No one over-all index or measure satisfactorily represents the combination of factors that must be taken into account. Thus, one cannot use a simple score or index to select the "best" alternative or combination of alternatives from the set of possibilities. Instead, to compare alternatives, one must resort to a more complicated (and seemingly less "scientific") procedure: (a) rate each alternative according to each criterion; (b) evaluate the ratings according to the external (non-pollution) criteria that are considered important (e.g., equitability, risk preferences, Federal, state or corporate budget limitations); and (c) compare the sets of evaluated ratings to identify the alternative or alternatives that then appear dominant. This procedure contains subjective elements and possible ambiguities, as indeed it must, for public policies are rarely clear-cut. Seemingly more exact methods contain them as well; they may merely hide them behind illusions of precision.

Evaluation is most legitimately carried out by the public through its elected representatives or those to whom they delegate the authority. The external criteria by which pollution-combating alternatives are judged often reflect the highest values of society, decided or revealed through the political process. Moreover, the tradeoffs between criteria—for example, between pollution reduction and impacts on particular groups—are subtly complex and often politically quite consequential. A bad rating on one criterion—for example, impact on the disadvantaged and poor—might be sufficient reason to rule out an otherwise attractive alternative. Such evaluation, however, should be made by the public explicitly and knowingly. An index that included all factors, evaluated tradeoffs, and combined the resulting value judgments into some single, merged criterion would implicitly usurp the public's authority and responsibility.

For similar reasons, "public acceptability" is here considered a criterion rather than a constraint. A myth, too long perpetuated in discussions of the problem, says experts (e.g., administrators, engineers, planners) can identify at some early stage those alternatives that will be unacceptable to the public and that, thus, should be developed no further.

This myth implies, first, that there are certain absolutes. In fact, experience suggests that "the community can be educated and public opinion can be changed, and that whether something is worth doing in the political arena depends on its costs and benefits." * Second, the myth implies that "experts" are more capable of determining political feasibility or public acceptability than policy makers or publicly responsible officials. But, in democratic societies, only the public and its elected representatives have the right to decide what is and what is not politically feasible or publicly acceptable. Experts are notoriously bad at making these judgments. Their responsibility is to provide information on the possible outcomes, costs, and benefits of alternative actions, not to decide that particular alternatives will be unacceptable.**

Constraints

Constraints are inflexible criteria that alternatives must meet. They usually reflect scarcities, rigidities, or values of over-riding importance, and change as these change with time. For motor vehicle air pollution, constraints on possible solutions arise because

(a) **Certain resources are scarce or limited**—e.g., technical manpower (numbers, specialties, quality), facilities, and knowledge. Knowledge, e.g., scientific knowledge and technical state-of-art, evolves rapidly, so that frequent re-assessment of knowledge constraints is necessary. Technical manpower is not likely to be a serious constraint (although there might be shortages in some specialties if, say, electric car development were to be pushed on a large scale), but some projects requiring similar specialties may be slowed or halted because of manpower diversion. Facilities, similarly, should be adequate for most purposes, although robust, reliable pollution measuring instruments and facilities for testing new components and systems may be scarce.

As the Subpanel on Automotive Energy Sources points out, shortages of certain materials (e.g., silver, mercury, and platinum group metals) might be ag-

gravated by the introduction and widespread use of some new propulsion systems but, otherwise, materials are not expected to be a serious constraint. The Subpanel on Automotive Energy Sources also has found that "adequate energy sources are available at least for the remainder of this century to meet the vehicle transportation requirements of the country regardless of the type of power plant that may be used."

For the scale of pollution-control that has been envisioned, capital is not likely to be scarce, both because the major firms involved (in the automobile and petroleum industries) are quite large and have extensive working capital, and because massive capital investments do not appear necessary.

(b) **Solutions must work in the current context and what evolves therefrom.** Any policy proposed to combat motor vehicle air pollution must work in the context of its time and of the future it seeks to affect. It should exert what influence it can to make the context more receptive, but must acknowledge its very limited ability to change the context quickly or significantly, or to alter significantly the direction or momentum of the changes that result from the sum of countless other forces. Any proposed policy, for example, must take into account the following:

(i) Despite the many minor changes that occur almost daily, most metropolitan areas experience major change only over decades, if at all. In many important respects, the metropolises of 1990 will look very much like those of today. The factors determining intra-metropolitan transportation demand and the resulting transportation flows are likely not to have changed greatly, although the scale and structure of the demand and flows may have changed to reflect changes in technology and income distribution. The current stock of housing, offices, stores, factories, streets, and highways is so large that proposals for major redesign or realignment of metropolitan areas must, to be realistic, have time-horizons of twenty years or more. Similarly, large-scale changes in the transportation system require such large investments and (in general) take so long to accomplish that their effects are felt only long after they are planned. Proposals to shape the context over the short-term must, realistically, aim at the margin to influence changes and try to mold that which is new.

(ii) The current stock of motor vehicles is large and growing, and ownership is diffused among a very large number of people. Further, motor vehicles are sufficiently long-lived that new vehicles intro-

*J. F. Kain, "A Re-appraisal of Metropolitan Transport Planning," Paper presented to the Commonwealth Bureau of Roads Symposium on the Economics of Roads and Road Transport, Melbourne, Australia, July 17, 1967, p. 7.

**Ibid, p. 8. Kain continues: Frequently in complex systems . . . the implications of particular alternatives are not at all apparent. As a result it is often not possible to estimate even crudely the possible benefits and costs of particular actions until they have been examined carefully and until the detailed arithmetic has been done. That the arithmetic is difficult to carry out in many instances and can only be roughly approximated in others is no excuse . . .

duced in any year make up only 10 percent of the total stock. Thus, initiating and continuing pollution control requires dealing with a large number of individuals and contending with the lags and maintenance problems caused by the slow flow of old vehicles out of the system.

Table 47 gives the number of motor vehicles registered in the United States for 1963 to 1966 and shows the range of projections for the numbers—by vehicle type—for 1975 and 1980. The table reveals that there were more than 90 million vehicles in the U.S. in 1966 and that the number is expected to rise to between 125-160 million by 1980.

Table 48 shows that, although the average age of the automobile population is about 6 years, the median life of an individual automobile is nearly 11 years, and that more than 10 percent of the cars produced in a given year are still in use 16 or more years later (although cars 16 years old or older constitute only 1 to 2 percent of the total automobile population at a given time). These figures show, for example, that even if all cars produced after a given date were to have extraordinarily low emission characteristics, it would be 6 years before the low-emission cars would make up 50 percent of the total car population, 9 years before they would make up 75 percent, and 14 years or more before they would have replaced all but 5 percent of the older cars.

TABLE 47. U.S. MOTOR VEHICLE REGISTRATIONS¹

Year	Passenger Cars	Buses	Trucks	Total
1963	69,055,000	298,000	13,360,000	82,714,000
1964	71,983,000	305,000	14,013,000	86,301,000
1965	75,261,000	314,000	14,795,000	90,370,000
1965 ²	74,913,000	155,000	14,035,000	89,103,000
1966 ³	78,315,000	15,864,000		94,179,000
Projections				
1975	95-115 million	20-25 million		115-135 million
1980	105-135 million	20-30 million		125-150 million

¹ Privately and Publicly Owned Vehicles, excluding military vehicles. Bureau of Public Roads data, cited in 1967 *Automobile Facts and Figures*, p. 19. (all figures rounded to the nearest thousand)

² Privately Owned Vehicles only.

³ Preliminary estimate.

⁴ Figures may not add precisely to totals because of rounding.

TABLE 48. AUTOMOBILE LONGEVITY¹

A Age of Car (Years)	Fraction of Cars (A-1) Years Old in Preceding Year Surviving to Become A Years old in		Fraction of Cars Originally Produced that had Survived A Years in	
	1963	1964	1963	1964
2-3	.999	1.000		
3-4	.999	.991	.999	.991
4-5	.990	.990	.990	.981
5-6	.974	.975	.964	.956
6-7	.957	.952	.922	.910
7-8	.936	.916	.863	.834
8-9	.906	.909	.781	.758
9-10	.856	.859	.669	.651
10-11	.813	.822	.544	.535
11-12	.780	.770	.424	.412
12-13	.764	.753	.324	.310
13-14	.769	.752	.249	.234
14-15	.752	.757	.187	.177
15-16	.773	.731	.145	.129
16+	.797	.825	.116	.107

Median Automobile Life = 11 years (approx.)

Average Age of Automobile Population = 6 years (approx.)

¹ Calculated from figures given in *Automobile Facts and Figures*, 1965, p. 22.

Truck replacement is even slower; it takes more than 7 years to replace 50 percent, more than 13 years to replace 75 percent, and 18 years or more to replace 95 percent.* These figures assume a reasonably steady rate of new production and no essential change in the current rate of scrapping old vehicles. An increasing rate of new production and an increasing rate of retirement could accelerate the influence of new vehicles.

Table 49 shows automobile ownership by household income in 1964. It shows that ownership of approximately 60 million automobiles was then divided among approximately 43 million households, of which roughly 12 million owned two cars or more. It also shows an almost perfect (in a statistical sense) correlation of automobile ownership with household income; the percentage of households owning one or more cars rises from 50 percent for households with incomes of \$2000 or less to essentially 100 percent for households with incomes of \$15,000 or more. If these figures truly represent discretionary uses of income and are stable with time, they may indicate that generally rising incomes (possibly augmented

*Reference 9, p. 25.

by an at least partially successful "poverty program") will lead to greater automobile ownership (and hence somewhat greater pollution problems) than anticipated in the projections in Table 47.

Table 50 shows the leverage possessed by the Federal government through its ownership and purchase of motor vehicles. It shows that the Federal government owns domestically more than 70,000 automobiles and 210,000 trucks, and purchases in a typical year—excluding military agencies and the Post Office about 9,000 automobiles and 15,000 other vehicles. Although these form an almost insignificant share of the total stock and flow of vehicles, the numbers are large enough and Federal purchases are sufficiently conspicuous that they offer considerable opportunity for the testing of new developments and the inauguration of special purchase requirements.

TABLE 49. AUTOMOBILE OWNERSHIP BY HOUSEHOLD INCOME, 1964*

	Households (Millions)	Number of Cars Owned	Number and Percent of Households Owning			
			One or More Cars		Two or More Cars	
			No.	%	No.	%
All Households.....	56.2	59.4	43.3	77	12.3	22
Household Income:						
Under \$2000.....	13.4	7.9	6.7	50	1.2	9
\$2000-2999.....	5.1	3.5	3.2	63	0.3	6
\$3000-3999.....	5.2	4.5	3.8	73	0.6	12
\$4000-4999.....	5.0	4.8	4.0	80	0.7	14
\$5000-5999.....	6.2	6.7	5.4	87	1.2	19
\$6000-7499.....	7.0	8.9	6.4	91	1.9	27
\$7500-9999.....	7.0	10.2	6.6	94	2.6	37
\$10,000-\$14,000.....	5.3	9.0	5.1	96	2.6	49
\$15,000 and more.....	2.0	3.9	2.0	100	1.2	60

*Based on data from a sample of more than 15,000 households in July 1964 by the Bureau of the Census. Cited in 1967 *Automobile Facts and Figures*, Automobile Manufacturers Association, pp. 36-37.

(iii) Operating these large numbers of motor vehicles each year consumes a large amount of fuel. As Table 51 shows, nearly 75 billion gallons of motor fuel were consumed in 1966, and from 105 to 130 billion gallons are expected to be consumed by 1980.

TABLE 50. MOTOR VEHICLES OWNED BY THE FEDERAL GOVERNMENT¹
(June 30, 1966)

Agencies	Sedans, Station Wagons and Ambulances	Buses	Trucks	Total
Civilian (Total)....	42,616	1,418	117,072	161,106
Military (Total)....	40,514	10,505	139,571	190,590
All (Total).....	83,130	11,923	256,643	351,696
Domestic.....	70,683	7,755	212,699	291,137
Foreign.....	12,457	4,168	43,944	60,559

GENERAL SERVICES ADMINISTRATION PURCHASES OF MOTOR VEHICLES (EXCLUDING MILITARY)²

Type of Vehicle	Number	Amount ³
Sedans.....	7,420	\$11,859,000
Station Wagons.....	1,498	2,802,000
Post Office Vehicles.....	14,586	24,008,000
Ambulances, Trucks, Buses, Trailers and Others.....	15,404	36,561,000
TOTAL.....	39,008	\$75,230,000

¹ Annual Motor Vehicle Report, General Services Administration, February, 1967.

² Records of Motor Vehicle Section, GSA. Purchases for Fiscal Year 1966.

³ Rounded to nearest \$1,000.

(iv) An important part of current and future contexts that seems difficult to influence directly is meteorology. Large-scale weather modification is being studied, but now and for the foreseeable future seems beyond more than minor control (such as cloud-seeding). Proposals have been advanced for "breaking" temperature inversions and other stagnant conditions that exacerbate the effects of pollution. But thus far none seems capable of harnessing the forces that would be needed to upset these conditions' stability.

Micrometeorology may be more amenable to man's control. Indeed, there are suggestions that urban construction has greatly influenced microclimates, and that good design could both enhance conditions favorable to dispersing pollutants and reduce the effects of those that tend to trap pollutants locally. Reducing pollution by affecting micrometeorology may in the end be difficult, but now the major constraints appear to be lack of information and lack

of institutional mechanisms through which micro-meteorology might even be considered in developing the urban context.

(c) **Policies must be concerned with institutions, traditions, and habits.** Strong efforts that attempt to change these elements quickly are not likely to be welcomed by those even indirectly affected.

Pollution policies, for example, must consider the structures of the automobile and petroleum industries. The former is characterized by a few very large firms and a host of much smaller, specialized suppliers. The large firms engage in oligopolistic (as distinct from classical) competition and, for reasons described in the main Panel report and the report of the Subpanel on the Automobile and the Economy,

TABLE 51. MOTOR FUEL CONSUMPTION

Year	Motor Fuel Consumption (billions of gallons)
1965	71.1
1966 (preliminary)	74.6
	Range of typical projections
1970	80-89
1975	90-110
1980	105-130

have long lead times associated with the design, tooling, and production of new developments. The petroleum industry contains about two dozen large, integrated* firms and a considerable number of medium-sized to small companies. Many of the smaller companies (which account for noticeable parts of selected markets) concentrate on exploration and production, refining, or marketing, but not all of these, and thus are more sensitive to vicissitudes in any one. New processes for various aspects of refining are continually being introduced, and old processes are continually being modified, but the proportion of total capacity replaced or substantially modified in a given year is usually small.

Other constraints on policies stem from

(i) Frictions and unresolved authority and responsibility in government.

(ii) Continuing legislative review of executive authority and short-term appropriations, at both state and federal levels.

*Vertically integrated, with capabilities for exploration, production, refining, distribution, and marketing. Many have both domestic and foreign operations.

(iii) The fragmented powers and relative ineffectiveness of many local governments.

(iv) Time-lags and confusion accompanying the establishment, staffing, and breaking-in of new agencies, agency functions, or administrative or enforcement systems.

(v) Traditional relations and mutual suspicions between industry and government.

(vi) Traditional industrial prerogatives and habits.

(vii) People's traditional prerogatives (e.g., freedom of mobility) and habits.

(viii) People's preferences (as conditioned by existing alternatives, advertising, and their current milieu) and the problems and time involved in attempting to change them.

(d) **Policies must be concerned with distributional effects.** What matters is not only the size of the pie of costs (or benefits), but how it is divided up. Proposed changes must take into account possible disproportionate impacts on certain parts of the population.

Some policies might (as the section on Impacts of Pollution Control Policies explores) have impacts considered quite undesirable by the disadvantaged and poor. These groups may value lightly the benefits received from reduced pollution (because compared to the other discomforts, and medical and economic problems they face, pollution may seem minor) and value heavily the costs incurred from pollution control. Further, some pollution-combating policies may be economically regressive, and affect the poor and disadvantaged adversely in strictly economic terms.

Pollution-control policies might also disproportionately affect other groups, such as parking garage owners and operators (if the addition of afterburners or engine redesign were significantly to increase the length of all cars), small companies supplying parts or fuel components that might be eliminated or required to change radically, store owners in areas where parking or traffic might be restricted, etc.

The important questions are how severely these groups may be injured and how serious their injuries are considered to be. Someone is almost always hurt by policies that distribute costs and benefits unevenly. Deciding whether policies should be constrained to avoid particular injuries to particular groups requires (a) detailed analysis to discover just what the effects are expected to be and (b) careful evaluation of the effects to see whether the costs of the injuries outweigh the costs of constraining the policies.

The constraints imposed because of distributional effects should be reviewed periodically to ensure that they do not acquire the status of immutable laws. Too often such constraints outlive their bases. They become "rules of thumb" that must be observed because no one knows or remembers the reasons for the original decision, which thus cannot be contested. Conditions may change markedly, but all too often the constraint remains in force.*

Criteria For Pollution Reduction and Costs

In evaluating possible pollution control policies, two of the most important questions are

- (a) How much do they reduce pollution?, and
- (b) How much do they cost?

In this form, both questions are deceptively simple. The criteria for pollution reduction and costs involve many considerations, as the following subsections show.

Criteria for Pollution Reduction

In evaluating the actual reduction of pollutants that might result from various policies, the key questions are

- (a) Which pollutants are reduced?
- (b) Which, if any, are increased?
- (c) By how much are they reduced or increased?
- (d) For (a) to (c), Where?
- (e) For (a) to (d), When?

Further important questions about a policy's pollution reduction are

(f) To which features of the policy are these results most sensitive? That is, if ten** percent more money than indicated were to be devoted to this policy, where should it be spent? Or, if only ninety percent of the money indicated were to be available, what should be cut and what should definitely be left alone?

(g) What happens to the pollution reduction claimed for other policies if this policy is followed, and vice versa? Which other policies would enhance this one, or be enhanced by it? By how much (i.e., questions (a) to (e))? Which other policies would lower the effectiveness of this one either by affecting it adversely or by getting rid of part or all of the

problem this one is designed to combat? Similarly, which other policies' effectiveness would this one lower? By how much?

In evaluating how effective given policies might be, one properly should weight specific pollution reductions according to their relative importance. Measures of importance (or of pollutant-reducing effectiveness) should assign weights to the specific pollutants reduced (or increased), the amounts of reduction (or increase), and the locations and times of the pollutant changes. With these measures, one should be able to answer in some reasonable way questions such as: Which of the (hypothetical) two programs outlined in Table 52 would be preferable on the criterion of pollution reduction?

Unfortunately, information is not now sufficient to develop meaningful measures of this kind, as the report of the Subpanel on Air Pollution shows. There appears to be little general agreement about either the relative importance of the various pollutants or the relative values of various reduced levels.

The questions about sensitivities and interactions can be handled with somewhat more confidence, mainly because they deal more with specific technical issues than with medical and public values. Interactions between certain technological alternatives are receiving attention now in a number of laboratories. Interactions between technological and non-technological alternatives have received perhaps less attention but may also be important. Proposals to reduce pollution by increasing the average speed of traffic through congested areas or by improving people's driving habits, for example, would be much less attractive if engine changes were to make emissions depend much less on speed and on frequency of acceleration, deceleration, and idle.

Sensitivities may be explored, at least approximately, through some simple, aggregated models that represent some of the more important phenomena and policy variables. Pollution effects can be reduced in three general ways.

- (a) By reducing the extent of the activity that produces pollution,
- (b) By reducing the pollutant emissions per unit of activity, and
- (c) By reducing the impact of emitted pollutants on susceptible people, agriculture, and property.

A relatively detailed, formal model (Model I) for (a) and (b), and a highly simplified, partially phenomenological model (Model II) for (c) are developed in appendices 1 and 2. The results of these models may be summarized as follows:

*Reference 143, p. 6.

**Ten percent is used for illustration. In practice, sensitivity should be examined for several different levels of expenditure above and below that indicated. The information revealed through sensitivity questions may lead to revisions of the policy which improve it greatly.

TABLE 52 PROGRAM A
(1-hour peak average concentrations-ppm)*

Year	CO	HC	NOX
1975—Central Area.....	30±5	15±5	0.6±0.3
Suburban Ring.....	10±3	8±5	0.3±0.1
1985—Central Area.....	20±5	10±5	0.8±0.4
Suburban Ring.....	8±3	6±4	0.4±0.1
1995—Central Area.....	15±5	6±4	0.5±0.3
Suburban Ring.....	6±2	3±2	0.3±0.1

PROGRAM B
(1-hour peak average concentrations-ppm)*

Year	CO	HC	NOX
1975—Central Area.....	35±5	17±7	0.5±0.4
Suburban Ring.....	10±3	9±6	0.3±0.2
1985—Central Area.....	25±5	11±5	0.5±0.3
Suburban Ring.....	5±3	5±4	0.2±0.1
1995—Central Area.....	5±2	1±1	0.1±0.1
Suburban Ring.....	2±1	0.5±0.5	0.05±0.05

*Expected values ± expected 95% confidence limits.
(1-hour peak average concentration may not be a good index; it is used for illustration only.)

MODEL I:

Nomenclature

(i) Subscripts

- j represents pollutants—i.e., $j = 1$ might represent CO, $j = 2$, ozone, etc.
- k represents distinct aspects of the driving cycle—i.e., $k = 1$ might represent steady driving below 10 mph, $k = 2$, deceleration, etc.
- m represents relevant vehicle types—i.e., $m = 1$ might represent small cars, $m = 2$, light trucks, etc.

(ii) Independent Variables

- R Region of interest, in which activity produces pollution, e.g., a certain part of downtown
- T Time period of interest, e.g., 8 to 10 a.m.
- y Year of interest, e.g., 1980
- y_0 Year in which a given vehicle was produced.
- a Age of a given vehicle, in years ($a = y - y_0$)

M Maintenance policy

(iii) Dependent Variables

- $N_m(y_0)$ Number of vehicles of type m originally produced in year y_0 .
- $N_m(y, a)$ Number of vehicles of type m that are a years old in year y .
- $S_m(a)$ Fraction of vehicles of type m surviving a years.
- $A_{jkm}(y, a)$ Amount of pollutant j emitted per unit of driving aspect k by vehicles of type m that are a years old in year y .
- $D_{jkm}(R, T; a)$ Extent of driving in aspect k done by a year old vehicles of type m in region R during time-period T .
- U_{jkm} Amount of pollutant j emitted per unit of driving aspect k by vehicles of type m that have no pollution control (i.e., base-line emissions).
- $E_{jkm}(y, a; M)$ Effectiveness of control on emission of pollutant j during driving aspect k from vehicles of type m that are a years old in year y and have been maintained with maintenance policy M .
- $f_{jkm}(a, M)$ Effect of vehicle age and maintenance policy on control effectiveness for pollutant j in driving aspect k for a vehicle of type m . $f = 1$ indicates that effectiveness is the same as when the car was new. $f = 0$ indicates that all of the designated pollutant control has been lost.
- $Q_{jkm}(R, T; y, a)$ Quantity of pollutant j emitted by an a year old vehicle of type m in region R during time T in year y .
- $Q_{jkm}(R, T; y)$ Total quantity of pollutant j emitted by all vehicles of type m in region R during time T in year y .
- $Q_j(R, T, y)$ Total quantity of pollutant j emitted by all vehicles in region R during time T in year y .

Relations

- (1) $N_m(y, a) = N_m(y_0) S_m(a)$
- (2) $E_{jkm}(y_0, 0) = [U_{jkm} - A_{jkm}(y_0, 0)] / U_{jkm}$
- (3) $E_{jkm}(y, a; M) = E_{jkm}(y_0, 0) f_{jkm}(a, M)$
- (4) $A_{jkm}(y, a) = A_{jkm}(y_0, a) [1 - E_{jkm}(y, a; M)] / [1 - E_{jkm}(y_0, 0)]$

$$(5) \quad Q_{jm}(R, T; y, a) = \sum_a A_{jtm}(y, a) D_{tm}(R, T; a)$$

$$(6) \quad Q_{jm}(R, T; y) = \sum_a Q_{jm}(R, T; y, a) N_m(y, a)$$

$$(7) \quad Q_j(R, T; y) = \sum_m Q_{jm}(R, T; y)$$

This relatively straightforward model (or collection of relations) relates substantive, measurable quantities—and the policies affecting them—to the rate of pollutant emission. Even in this simple, deterministic form it may facilitate the comparison of alternatives and permit the effects of policy and performance variations to be examined systematically.

MODEL II:

The preceding model covers the production of pollution. To see what happens once pollution joins the atmosphere requires a detailed set of models that cover steps (g) through (k) of the air pollution chain of events (page 330). Current understanding of meteorological (and atmospheric chemical) processes is not sufficient to develop such models. Nonetheless, it is possible to develop an extremely crude, highly oversimplified model of the generally important events that offers some indication of how some key phenomena and policy variables might interact. Such a model is developed in appendix 2. It is included only to show in a rough, semiquantitative way what the broad implications of certain policies might be. It is not meant to be definitive, and should be interpreted more broadly than below only with considerable caution.

Nomenclature

- c_j = Average concentration of pollutant j in a given region
 d = Characteristic over-all dimension of a given region (e.g., diameter, length, width)
 D = Effective atmospheric diffusion coefficient
 k = Rate at which pollutant j is effectively removed from the atmosphere
 S_j = Rate of emission of pollutant j in a given region (in the sensitivity calculations, assumed to be uniform throughout the region)
 V = Wind velocity (assumed constant)

Relation

$$C_j \cong \frac{S_j}{k} \left[1 - \left(\frac{V}{kd} \right) \left(1 - \exp \left(-\frac{kd}{V} \right) \right) + \frac{kD}{V^2} \right]$$

Sensitivities

Despite its many limitations, this simple model may show approximately how sensitive the average pollutant concentration is to changes in emission rate, pollutant removal rate, wind velocity, and regional size. The index of sensitivity used is the percentage change in average pollutant concentration that might be expected to result from a one percent change in the indicated quantity, with everything else remaining constant.

(i) Emission rate: S_j

A one percent **decrease** in emission rate might be expected to result in roughly a **one percent decrease** in average pollutant concentration.

(ii) Pollutant removal rate: k

A one percent **increase** in pollutant removal rate might be expected to result in a **decrease of b percent** in average pollutant concentration, where

$$b \cong \frac{1}{3} \left(\frac{kd}{V} \right).$$

For a region in which $k \sim 1/\text{day}$, $d \sim 5$ miles, $V \sim 7$ miles per hour, $b \sim 0.01$. Thus, it appears that pollutant concentration is at least an order of magnitude less sensitive to changes in the rate of pollutant removal from the atmosphere (by physical and chemical means) than it is to changes in the emission rate.

(iii) Wind velocity: V

A one percent **increase** in wind velocity might be expected to result in roughly a **one percent decrease** in average pollutant concentration.

(iv) Atmospheric dispersion: D

This model represents a physical situation in which atmospheric dispersion is not important (its effect is less than that of the pollutant removal rate). Dispersion is important, however, when pollutant concentrations change significantly over relatively short distances.

(v) Regional size: d

A one percent **increase** in the size of the region over which pollutants are emitted at a uniform rate might be expected to result in roughly a **one percent increase** in average pollutant concentration. This result has implications regarding the pollution effects of urban sprawl.

Criteria for Costs

In evaluating the net monetary costs that might result from various policies, key questions are

(a) What are the monetary costs to the consumer?

(b) What monetary benefits does the consumer receive?

(c) How are these costs and benefits distributed among consumers?

(d) For (a) to (c), When?

Further important questions about a policy's costs are

(e) What are the secondary costs or benefits to the consumer that result from changes in governmental tax revenues or government expenditures?

(f) What is the distribution of probabilities for future costs? That is, what are the likelihoods of actual costs in given future years being ten percent less than those estimated? Ten percent more? Fifty percent more? Twice those estimated? Five times those estimated?

(g) What interest (or equivalently, discount) rate is used for comparing alternative policies?

(h) For policies where reduced pollution is only one of many desired goals, what procedure is used to allocate part of the costs or benefits to pollution control?

We stress the consumer in questions (a) through (e) because the consumer's point of view should be maintained throughout (i) to show what the ultimate monetary costs and benefits to him might be and (ii) to avoid double counting. The latter is especially important because without a consistent point of view it is easy to count the same costs over and over again.

Technological changes, for example, may raise initial purchase prices of automobiles; these increases would be costs to car-buying consumers. These same changes may have entailed research, development, and tooling costs for automobile manufacturers, research and development costs for metals producers and parts suppliers, etc. But all these costs are represented in the automobile purchase prices and should not be counted again. The increased revenue from the increased prices balances these costs for the companies concerned, so that the net (primary) cost for the economy is that felt by the consumers. Similarly, if pollution control were to increase fuel "mileage," that is, decrease the number of gallons of fuel needed to drive a given distance, the net (primary) benefit would be the net savings to the car-operating public; including the effects on petroleum company revenues, etc., would be double counting.

Distributional effects may be important if costs or benefits are distributed quite unevenly. If, for example, pollution control changes were to increase

the prices of inexpensive vehicles and decrease their fuel mileage, yet not affect the prices of more expensive cars and increase their fuel mileage, one would want to consider the distribution of costs as well as the over-all total.

When net costs occur is important because (i) their timing may affect consumers' ability or willingness to pay them and (ii) money can earn interest, so that costs incurred today are valued at more than the same costs incurred some years from now. How different the valuation is at different times depends on the interest rate—question (g). Selection of an interest rate is discussed in the following section.

Secondary costs and benefits accrue to consumers through the effects policies have on government receipts and expenditures. Decreased fuel consumption, for example, would result in decreased fuel taxes to states (about 6 cents of the price of a gallon of fuel is state tax) and to the Federal government (4 cents per gallon is Federal tax). Most of these taxes go into special highway funds that are kept separate from general treasuries, however, so that it is difficult to trace directly the effects decreased revenue would have. Highway programs might be curtailed or stretched out, or possibly reorganized; what these steps might mean to consumers (and when) is not clear. Increased vehicle purchase prices might result in increased state revenues in states having sales taxes on vehicles and might result in increased Federal revenues through the corporate profit tax. Tracing the effects of pollution control costs and price increases through corporate ledgers to see how they affect profits, however, is likely to prove unrewarding, and tracing the effects of slightly increased tax revenues on consumers is likely to be difficult. Thus, one might assume most secondary effects to be negligible unless they clearly are not.

In evaluating policies, it is important to recognize that many costs, especially those associated with incompletely developed technologies, are quite uncertain. Many are only guesses, based on conjectures and preliminary information that may later prove to be wrong. Careful application of the techniques of "technological forecasting" * may help to bound cost estimates. But no technique, no matter how ingenious, can yield more than probabilistic estimates of the costs (or benefits) that might stem from alter-

*For a discussion of "technological forecasting" see M. Cetron, "Forecasting Technology," *International Science and Technology*, No. 69, 83-92 (September 1967).

naives that have never been tried or do not yet exist. The best that now seems possible is to choose carefully an expected value (or "best guess") of the costs and benefits, based on the information and insight available, and then to fill out an approximate (subjective) probability distribution by answering the latter part of question (f).

Using the expected value alone is hazardous, unless there are very good reasons to believe that the costs cannot differ greatly from it. An error of \$1 per vehicle in estimated present value is an estimating error of about \$100 million—a small part of the GNP but significant nonetheless. If the costs are uncertain, as they surely are for some policies, policy makers and the public should know how uncertain, so that they can choose and plan accordingly. In some cases, incurring additional costs for experimentation and careful monitoring may reduce uncertainty significantly; deciding whether such expenses are worthwhile entails having some idea how uncertain the estimates might be without the additional knowledge.

When vehicular pollution control was thought to involve merely adding on devices without essentially changing vehicles any other way, assigning costs to pollution control appeared straightforward. Now that technological pollution control appears to involve basic engine redesign, deciding how much of the redesign cost to charge to pollution control is no longer so simple. Some redesign might occur as part of some year's model change even without the impetus of pollution. And, if it is thorough and well done, the redesign may improve aspects of vehicular performance other than pollution. These other improvements are not valueless. Similarly, redesigning may alter some performance aspects undesirably; how much of the "degradation" should be charged to pollution control and how much to other design trade-offs (such as are made normally) is not immediately clear.

Many of the non-technological alternatives proposed serve mainly other objectives; for them, pollution is an incidental consideration. If increased consumer costs for these do reduce pollution, however, even incidentally, some of those costs might legitimately be charged to pollution control. Determining how much should be charged is much like determining the cost of a secondary by-product, a problem that has not been satisfactorily resolved, even in industries where such by-products are common.

These allocation problems make determining the

"cost of vehicular pollution" either extremely difficult or very arbitrary. Proposals for tax incentives, cost sharing, or accelerated depreciation to stimulate pollution control investment must face these problems; otherwise they would seem likely to have more effect on accounting procedures than on research and development or design and production.

Interest Rates for Comparing Alternatives

As previously mentioned, interest causes costs and reduced pollution occurring in the future to be valued less than the same costs and benefits occurring now. Comparing alternatives formally for pollution reduction and costs, therefore, entails selecting an interest rate. The following table shows the effect of the interest rate chosen:

Annual Interest Rate ¹	Value of Cost or Benefit Now	Relative Value of Cost or Benefit Occurring	
		10 years from now	20 years from now
1%	\$100.	\$90.53	\$81.95
2%	\$100.	\$82.03	\$67.30
3%	\$100.	\$74.41	\$55.37
5%	\$100.	\$61.39	\$37.69
10%	\$100.	\$38.55	\$14.86
20%	\$100.	\$16.15	\$ 2.61

¹Compounded annually

A low interest rate assigns relatively high importance to the future, whereas a high interest rate focusses almost entirely on the present and neglects all but the relatively near future.

There is an enormous literature on the subject of interest rates which we shall not attempt to review. We merely point out that for problems such as vehicular air pollution, the future is usually considered quite important, so that the interest rate used is usually rather low. The "social interest rate" reflects a different emphasis on the future than the competitive-market interest rate. We may wish cleaner air for ourselves, but even more we desire its benefits for future generations. Because of the significant differences between the probable effects of private and collective action, most people agree that the community as a whole should undertake more investment than each person would undertake individually. Each views his own sacrifice as a small price paid to get others to cooperate in making the investments he wants.* Thus, in evaluating air pollu-

*S. A. Marglin, Chapter 2 in *Design of Water-Resource Systems*, A. Maass (Ed.), Harvard University Press, 1962, pp. 47-48.

tion policies, the future should be valued highly, the interest rate chosen should be lower than that used in evaluating private investments.

Criteria For Effects On The Motor Vehicle System

Pollution control policies may affect the motor vehicle system *per se* by

(a) Changing performance characteristics such as range, acceleration, rate of acceleration, "optimum" speed, maximum speed, lighting, rapidity of starting, adaptability to different environments (heat, cold, dust, wind, rain, snow, ice), capacity (for people and goods), versatility (or flexibility), and reliability.

(b) Changing the qualities of comfort by affecting noise (level and character), vibration, environmental control (heating, air-conditioning), accessories (radio, cigarette lighter, power steering, power brakes, power-operated windows, etc.), and status value.

(c) Affecting safety. The "boundary conditions" for safety design are not now known with certainty; many of those now in lawbooks are basically arbitrary.

(d) Changing convenience characteristics such as ease of starting, ease and rapidity of refueling, frequency and extent of maintenance, ease of parking, ability to handle goods and people, and compatibility of parts with the rest of the motor vehicle and transportation system.

The criteria for evaluating these effects are not well understood, but the effects are important, nevertheless. Public acceptability is an important criterion, for example, but one shrouded in myths and mystique. The public's criteria for these effects are obviously interrelated. Some people may be willing to trade capacity and certain features of comfort for greater acceleration, maximum speed, status value, etc., as they now do when they buy sports cars. Other people prefer small, lower performance cars, and still others prefer station wagons, large cars, pick-up trucks, etc. The current spectrum of performance, comfort, safety, and convenience characteristics is relatively broad. And the car-buying and car-operating public is diverse in its needs, desires, perception of what is available, and ability to pay. Thus it is difficult to lay down universal criteria for "public acceptability" other than those which ensure that vehicles will perform "satisfactorily" in the road environment.

Basic criteria for such satisfactory performance are given by the Subpanel on Energy Storage and Conversion Systems. Additional requirements, as yet not completely understood, are imposed by inter-

sections, expressway on-ramps, altitude, rural roads, and traffic that includes a wide variety of vehicles. Traffic performance may be quite important as a criterion for electric vehicles that have limited acceleration. Preliminary theories indicate that the susceptibility of traffic to "instabilities" and collisions may increase as the range of vehicle acceleration abilities increases.¹¹ Furthermore, having even moderate numbers of slowly accelerating vehicles in heavy traffic could seriously degrade traffic flow.

Evaluating the safety of new vehicles (and, to a lesser degree, of other pollution-combating alternatives) will be an administrative problem for the Department of Transportation, which is responsible for formulating Federal safety regulations. It should not be assumed that serious problems will be obviated because electric vehicles—as now being tested—are to be used mainly in relatively low-speed town driving. A high proportion of fatalities occurs in accidents involving vehicles that were driving between 20 and 40 miles per hour. Attention must be given to the interactions between electric and regular vehicles, and to means of protecting the driver and occupants of electric vehicles, if a noticeable number of electric vehicles appears on the roads.

Pollution control changes may also affect more than just vehicles. For evaluating electric vehicles, for example, support hardware (e.g., electric charging facilities), system maintenance, command and control (e.g., direct communication with vehicles to indicate best routings, etc.), traffic assignment (e.g., rights of way), and system-cost should also be taken into account. One should also examine possible impacts on transportation system design. It seems, for example, that

(A) Emission reduction would greatly facilitate the design and construction of tunnels and partially or totally underground highways. Ventilation requirements now significantly limit the extents of both tunnels and underground roads, and greatly increase the costs of building and operating them. Major reductions of ventilation requirements that would ensue from major reductions of pollutants would free designers from current constraints and save taxpayers' dollars.

(B) Emission reduction, especially if accompanied by significant noise reduction, would permit extensive use of the air-space over highways. Occupants of the few structures now built over highways suffer greatly from automobile-caused dirt, fumes, and noise.* But,

*The New York Times, June 20, 1967, p. 42.

for the long run, use of highway air-space for buildings or for integrated "linear cities" is felt by many to be quite important. In many cities roads (and access ramps) use large amounts of land and destroy neighborhood integrity. Development of highway air-space might offset such effects, but highway air-space is likely to be developed only if automobile emissions and noise* are substantially reduced.

(C) Improving local meteorological conditions requires careful highway design that takes account of prevailing winds and attempts to reinforce rather than negate them.

Administrative And Economic Criteria

Policies to control vehicular pollution should be consistent with the following administrative and economic principles:

(1) **Policies should permit decisions to be as decentralized as possible.** For example, other things being equal, a rule that emissions "be reduced by a certain amount is preferable to a rule that particular devices be installed, since the former permits alternatives to be considered that may be cheaper than the devices specified in the latter."**

(2) **Policies should be flexible and consciously experimental.** As experience accumulates, information will be gained about the problems, costs, and benefits of pollution control. We will then revise our ideas about desirable amounts and methods of control, and have to revise control schemes accordingly.*** Policies covering uncharted ground should consciously include experiments carefully designed to yield meaningful experiential information as soon as possible.

(3) **Policies should attempt to expand future "freedom of choice."** To increase the opportunities available in the future, rigid, inflexible, long-term commitments should be avoided. And policies should, whenever possible, be designed so that more options or choices will be available in the future than were

available when the policy began.

(4) **Policies should seek to minimize administrative complexity.** Other things being roughly equal, policies that require fewer formal procedures, fewer detailed regulations, and fewer administrative and enforcement personnel are preferable. Considerable attention should be given to devising policies that might at least partially enforce themselves, e.g., by offering a combination of positive and negative incentives—with built-in social or economic feedback—that might encourage people to reduce pollution without direct regulation.

(5) **Policies should seek to attain finer control.** Policies should seek to recognize the finer details of pollution control, e.g., that not all pollutants at all times in all places are equally undesirable. Adopting pollutant mass emission standards rather than concentration standards would also be a step in this direction.

(6) **Policies should strive to improve means to measure and monitor pollutant emissions, concentrations, and effects.** Ability to measure and monitor lies at the heart of virtually all pollution control. Many of the other criteria in this section would become meaningless without better means, so that developments in measuring and monitoring should be given high priority.

(7) **Policies should be coupled with careful economic research and system experimentation.** We now know so little about the costs and benefits of various forms of pollution control that choosing wise policies is difficult. Without some form of benefit-cost evaluation, it is hard to determine desirable amounts or means of abatement. Without some form of system experimentation and concurrent economic research, not much about benefits and costs is likely to be learned. Thus, well designed schemes of experimentation and research should be emphasized in connection with any control policy.

(8) **Policies should emphasize learning on the part of the public, industry, and government.** Because we now know so little about so much, the public, industry, and government are susceptible to rumors, myths, and misinformation. All need consciously and systematically to learn from accumulated experience; thus, policies should emphasize and facilitate such learning.

(9) **Policies should take into account possible major risks and contingencies.** How one accounts for risks and contingencies depends upon one's optimism about the future and one's inclination to gamble. But major contingencies (such as unforeseen

*For this purpose noise is a lesser problem than emissions, but is serious nonetheless. Proper insulation and acoustic baffling can do much to reduce the fraction of road noise that reaches people's cars. But even with such design, noise levels may still be annoying to some unless vehicle noise emissions are reduced.

**E. S. Mills, "Economic Incentives in Air-Pollution Control," in H. Wolozin (Ed.), *The Economics of Air Pollution*, W. W. Norton & Co., New York, 1966, p. 42.

***Ibid., p. 42.

chronic medical effects of certain pollutants, possible inadvertent weather modification, possible major risks should biological pollution scavengers be used, etc.) should be taken into account, and provided for if evaluation indicates that the likelihood of occurrence and danger so warrants.

(10) **Policies should strive to be equitable.** Equitability (or "fairness"), of course, depends on one's point of view. Nevertheless, equitability has been and remains an important criterion for American public policy, especially for evaluating policies that appear to allocate or distribute benefits and costs unevenly.

(11) **Policies should realistically take into account their leverage over the events they seek to control.** Some policies proposed to combat vehicular pollution—e.g., modifying urban form—have little influence over or real ability to control the factors that will determine whether they succeed or fail. The probability of such policies resulting in what they aimed for is thus exceedingly small.

(12) **More efficient control can normally be obtained by incentives that depend on the variable one desires to influence rather than by incentives that depend on a related variable.*** Penalties, incentives, or regulations that depend on the amount of pollutants discharged are likely to be more efficient than, for example, those that depend on automobile mileage. The latter would distort resource use in favor of other transportation modes and against better emission controls, and would thus be influencing the wrong things.

(13) **Payments or subsidies are subject to the following problems**** (in addition to cost-allocation problems):

(a) **There is no natural "origin" for payments or subsidies.** "In principle, the payment should be for a reduction in the discharge of pollutants below what it would have been without the payment. Estimation of this magnitude would be difficult and the recipient of the subsidy would have an obvious incentive to exaggerate the amount of pollutants he would have discharged without the subsidy."

(b) **Payments or subsidies violate feelings of equity.** People feel that if polluting the air is a cost of certain activities, then those who benefit from those activities ought to pay the cost.

(c) "If the tax system is used to make the payments, e.g., by permitting a credit against tax liability for reduced [emissions], a 'gimmick' is introduced

into the tax system, which, other things being equal, it is better to avoid. Whether or not the tax system is used to make the payments, the money must be raised at least partly by higher taxes than otherwise for some taxpayers. Since most of our taxes are not neutral, resource misallocation may result."

(14) **Policies should take into account "spill-over" costs and benefits.** Certain policies that, for example, stimulated the use of electronic controls on motor vehicles might facilitate the eventual introduction of automated traffic control, with its attendant effects on congestion. Policies that reduced downtown parking in order to cut down on the number of polluting automobiles might seriously affect downtown commerce. Policies that reduced motor vehicle noise as well as chemical pollution might have significant impact on the values of property within earshot of busy streets and highways.

(15) **Policies should consider the possible impacts of pollution reduction on alternative forms of medical care.** (This criterion appears to be of minor importance now, but might be kept in mind as the medical effects of pollutants become better understood.)

Criteria For Federal Role

Agreement on criteria for the Federal role is scarcely unanimous, for the extent, scope, and nature of Federal concern in any question have become polarizing issues in contemporary politics. However, the Federal role appears logically to include protecting the public interest, especially in matters such as health where the "market" is highly imperfect, and coordinating and stimulating private activities to insure that the public interest is, indeed, protected adequately. Also, although the Federal Government has not always handled this responsibility well, it should attempt to ensure that the long-run is adequately considered, i.e., that short-range problems do not drive out long-range planning.

More detailed questions, such as the best combination of industrial stimulation and Federal in-house research, lie beyond the scope of this report.

Part of the Federal role also involves sustaining high-quality professional interest in technical areas related to air pollution. To attract excellent talent, continuing emphasis and funding will be needed. Young professionals beginning their careers and well-established professionals who might be attracted by the challenge will work in air pollution only if it appears to hold promise of remaining an important field for at least several years. Thus, it is important to avoid short-term "kicks" or faddish interests that

**Ibid.*, p. 44.

***Ibid.*, p. 45.

decline quickly, and to establish provisions for long-term support sufficient to develop a "critical mass" of research and to influence the interests and skills of those still in the educational "pipeline."

In addition, the Federal role involves coordinating the various Federal interests, ensuring United States participation in international endeavors, and facilitating the flow of information and technological results among those working to solve the vehicular pollution problem.

An important question that will become increasingly important is the traditionally thorny issue of Federal-State roles and relations. States, particularly California, have been pioneers in combating vehicular pollution and remain very active and conscious of their problems, which continue to grow. Some, particularly California, have problems caused by motor vehicle concentrations and unfavorable meteorology that exceed those recognized elsewhere and which, in their view, require standards stricter than those now or to be imposed nationally by the Federal government. These states are understandably concerned about the Federal government's possibly preempting the field of emission control and thereby preventing them from achieving the more rapid progress they seek.

The administrative and economic criteria outlined in the preceding section seem to point toward these states' view. The air pollution problem is national in scope and importance; the externalities involved do dictate government action; and the problems that might be posed by a welter of conflicting local regulations do indicate that national action is desirable. Yet decentralization, flexibility, administrative complexity, fineness of control, and equitability all point toward "air shed" or localized standards (possibly embedded in national regulations) as the best policy. Public health programs have long been guided by the sound principle of "treat the problems where the problems are." One may have national minimum standards for certain aspects of health, but one should scarcely deny tighter standards to states that have problems more serious than the average; that would effectively mean denying those citizens their equal protection under the law, since the effectiveness of protection depends on the magnitude of the problem as well as on the cure.

Incentives

The Federal Government and several state governments have provided strong incentives for motor vehicle pollution control through emission standards.

These standards, discussed more fully in the sub-panel report on Air Pollution, have set maximum limits for selected pollutant concentrations in new cars' exhausts.

Other incentives for change would be:

(a) Other performance requirements related to pollution—e.g., standards based on pollutant mass flow rather than on concentrations.

(b) Grants for research or development on, or application of new technology or new system-management practices.

(c) Direct taxes (possibly related to emissions) on vehicles not meeting pollution control standards.

(d) Regulations or laws designed to affect use preferences or effect system management.

One action of interest to people concerned with cities that might indirectly stimulate pollution control is to require major urban highways to be located partially or totally underground. The main additional construction costs of underground highways relative to above-ground highways stem from tunnelling and ventilation.* For long stretches of underground highway, ventilation costs can be quite large. The emission reductions that would result from pollution control would permit significant reductions in the air-circulation rates (and hence the equipment and power) needed to ventilate tunnels and underground roads. Stimulation of underground highways thus would increase the incentives for pollution control (by adding a significant new benefit).

ALTERNATIVES

This section identifies a broad spectrum of alternative policies to combat vehicular pollution. The spectrum encompasses technological and non-technological approaches and some that are a mixture of both.** The section has three basic purposes: to depict the full range of pollution control possibilities.

*These costs are partly offset by reduced land acquisition and easement costs, reduced social dislocation, possibly reduced costs of utility relocation, etc.

**The character of these alternatives is relatively uneven. Although the report's structure may appear to indicate that all the alternatives discussed are roughly parallel, they clearly are not. The technological alternatives are in general more straightforward, more amenable to direct application, and less likely to induce major social and economic side-effects. The non-technological alternatives are more difficult to effect and involve more social dislocation and possibly unpleasant side-effects. Technological alternatives clearly should receive highest priority. If they are able to solve the problem, no further action is necessary. If they are not able to solve the vehicular air pollution problem, and the problem remains serious, then some of the relatively more attractive non-technological alternatives may be justified.

to indicate approximate evaluations or rankings of the alternatives, and to point out areas where new efforts might be fruitful.

The section consists of four parts, which cover (1) policies to reduce the level of activity that leads to pollution, (2) policies to reduce the amount of pollution emitted per "unit" of activity, (3) policies to reduce the impact of pollutants that are emitted, and (4) possible impacts of various policies on certain disadvantaged groups and the national economy.

Alternatives To Reduce The Level Of Polluting Activities

In designing approaches to reduce the level of polluting activity, one must take into account

- (a) The kind of activity to be reduced.
- (b) Where one wishes to have it reduced, and
- (c) When one wishes to have it reduced.

To keep costs* as low as possible, control policies should be as specific as possible. One should not, for example, decide to reduce all motor vehicle travel at all times in all parts of a metropolis without first determining whether reducing acceleration and deceleration during summer morning hours downtown might achieve nearly the same reduction in pollution effects with, possibly, much less dislocation and cost.

One might, thus, reduce the level of polluting activity by

- (a) Reducing the total amount of urban transportation.
- (b) Reducing the total amount of motor vehicle travel throughout a metropolitan area
- (c) Shifting some of the demand for motor vehicle travel to less polluting modes of transportation.
- (d) Reducing total motor vehicle travel in severely affected areas
- (e) Reducing all motor vehicle travel in affected areas at affected times.
- (f) Reducing the extent of motor vehicle travel in especially polluting aspects of driving (with possible further qualification to specific areas and or times)
- (g) Reducing travel by more highly polluting vehicles.

Reducing The Total Amount Of Urban Transportation

There are basically two ways to reduce the total amount of urban transportation: to reduce the de-

mand and or to restrict the supply. To reduce the demand, two main approaches have been proposed. The first is to redesign sections of metropolitan areas to reduce need and demand for transportation, and to so design new areas. The second is to substitute communications services for direct transportation. The following paragraphs discuss each of these, in turn.

The lengths and frequencies of trips in a metropolitan area are functions of its structure as well as of its transport system and socio-economic characteristics. The relationships of homes to jobs, and to shopping, cultural, educational, and recreational facilities strongly influence the over-all amount of metropolitan travel. It has thus been suggested that the total demand for transportation might be reduced if one could

(i) Provide better spatial integration of residences and offices in communities, to reduce the home-work place separation. At one extreme, this could involve recreating villages or village-like environments that would be relatively self-contained. Although, such environments might be attractive to some, they would very likely reduce the range of choices in jobs, social contacts, etc. available to metropolitan residents and thus do away with a lot of the advantages now found in city living. A more moderate version of the same proposal might involve revising zoning practices to permit greater intermixing of residences and offices throughout metropolitan areas. This version entails less radical change than the other, but still suffers from lack of leverage on the part of planners and the inertia of the current context.* Evidence suggests, too, that the few new "mixed" communities of this type built thus far have not reduced transportation significantly. People who have bought the houses have continued to work elsewhere, and most of those who have come to work in the communities have continued to live elsewhere even though so doing has often entailed long commuting.

(ii) Substitute elevator for ground transport by judicious use of tall buildings. Tall buildings abet urban concentration, which has been both strongly supported and strongly attacked in the last few decades. To oversimplify the opposing arguments, a few tall buildings do not make a city, too many too near each other may cause enormous congestion (and parking problems), and too much employment density may lead back to the work-residence separation (i) was designed to solve. New York has many

*Including those stemming from adverse effects of reduced activity levels.

*See pages 120-122.

tall buildings, yet has—considering its weather—a vehicular pollution problem as severe as that in Los Angeles (which has fewer tall buildings, spread over a larger area). Careful study of particular areas will be needed to show what the net effect of tall buildings are likely to be.

(iii) Redesign Federal regulations and financial procedures to encourage developments containing homes, apartments, and jobs, to minimize the number of new "bedroom" communities miles away from places of employment.

(iv) Rebuild urban renewal areas and post-riot areas in ways that minimize the need for transportation. With careful analysis and design taking into account the items mentioned in (i), these steps might eventually have the kinds of effects desired. Yet they are inherently very long-term measures and inherently limited by the scale of the new areas. Moreover, the transportation demand affected by (iii) is likely to be reduced (if at all) in areas where pollution is not now serious.

The substitution of communications services for direct transportation has been a popular theme in projections for the future.* It has been forecast that phonovision, closed-circuit television, facsimile transmission, remote computer operation, and devices yet unforeseen will make travelling all but obsolete. Yet evidence thus far suggests that transportation and communications reinforce each other: the better the communication the more transportation, and vice versa. Communications make available wider ranges of contacts and opportunities, and make it easier to maintain those contacts—which, in turn, generate travel. Better communications also facilitate some kinds of spatial decentralization,** which do not seem to decrease the need for transportation.

Further, it is possible that even if substitution of communication were to remove the need for commuting and shopping travel, the time freed might be allocated to other activities (e.g., educational, social, recreational) that demand transportation. In such instances, no net reduction of transportation demand might result. There appear to be many opportunities for substitution of communications for transportation, and vice versa, but they appear to be found in a context where there is much higher utilization of both.

Policies proposed to restrict the total supply of

transportation generally rely on regulation. Proposed regulations include (a) automobile production quotas, (b) deliberately slowed programs of road improvement and construction, (c) gasoline production and or sales quotas, (d) travel permits, and (e) regulations limiting bus, truck, and airplane use. All of these entail significant social costs. And, as pollution control measures all are too gross and too encompassing to be truly effective.

Even if total transportation were to be reduced, the remaining transportation might well be reallocated primarily to pollution-affected areas. In compensating for the restricted total supply, transporters and travellers might concentrate the remaining supply in the areas where it yielded the most return, creating severe pollution problems in these areas or aggravating problems that already exist.

Reducing The Total Amount Of Metropolitan Motor Vehicle Travel

Basically, there are three ways to reduce the total amount of metropolitan motor vehicle travel: regulation, pricing, and shifting demand to other transport modes. The last is covered in the next section.

Regulation might involve (a) fuel rationing, using any of a graded spectrum of schemes, (b) limited registration of second and third cars (based on "evidence of need") in the metropolitan area, (c) extremely tight enforcement of traffic laws, (d) motor vehicle travel permits (i.e., rationed travel), etc.

Pricing might involve (a) substantially increasing fuel taxes throughout the metropolitan area and its environs and (b) substantially increasing vehicle registration and operator's license fees throughout the area, to reflect the cost of air pollution in the expense of automobile operation. In conjunction with (c) above, it might also include increasing fines for traffic violations.

The regulations impose important social costs and interfere with citizens' "right of mobility." Rationing of fuel, vehicles, and travel itself has been attempted in wartime to force reallocation of resources away from consumers to war production and use. Even in national emergencies with much public cooperation, such rationing has distorted resource allocation and created social discontent. Without obvious scarcities or emergencies to justify such measures, one would find them extremely unpopular, very difficult to administer, and eagerly subverted. Their possible effects on the metropolitan economy would be more difficult to gauge, but would probably not be good.

*See, e.g., A. C. Clarke, *Profiles of the Future*, Harper & Row, New York, 1963, Chapter 16.

**Reference 190, pp. 15-17.

The pricing schemes tamper less with normal economic and social functions but may lead to misallocation and maldistribution of resources without successfully reducing pollution. The schemes, for example, are all economically regressive. They thus affect most those with lower incomes, who own fewer vehicles and drive those they do own less than the overall average.

Like the schemes in the previous section, these are too blunt to reduce pollution efficiently, and are broad enough to result in adverse social costs and distributional effects.

Shifting Demand To Less-Polluting Modes Of Transportation

Electric Vehicles

As the Subpanel on Energy Storage and Conversion Systems has shown, electric cars need be considered for pollution-reduction only over the long-term. They are not expected to have any significant impact until at least 1980. Estimating possible demand for electric vehicles then is difficult because long development and testing is needed before it will even be clear whether any will find use on the roads two decades hence. And, if the new cars are truly as different and new as their most enthusiastic advocates claim, they will radically change the relationships between existing transportation modes and tend to create their own specialized markets.

Even ordinary projections for 1980-1990 run into serious problems. But about the cars for which 1980-1990 demand is now being estimated we do not know: technology, performance, costs (initial or operating), role, or legal status vis-a-vis internal combustion engine automobiles. We also have no good idea what concurrent developments in the internal combustion engine, mass transit, and dual-mode systems will have taken place by 1980 or 1990. Not surprisingly, therefore, estimates of demand for electric cars range widely.

Some pessimists predict that only a curious, venturesome, and "stylish" few will ever want to drive electric cars.

The Gallup Poll* asked a cross-section of adults:

Here is a question about an electric automobile. First, let me tell you a little about it, and then I would like to get your opinions on it . . .

The car would be used for travelling about town—that is, for shopping and the like. It would have a top speed of about 40 miles per hour

and would go about 150 miles before the batteries would have to be recharged, which could be done at home. The car would be small and easy to park and would sell for about \$2,000. Do you think you would be interested in buying such a car?

Of the cross-section, 18% said they would be definitely interested; according to the Poll, this response translates nationally into approximately 10 million families.

Three reasons for interest in electric automobiles were cited most often: Economy, air pollution, and ease of handling. The citation of economy is interesting in that Zwick* claims that economy (minimum cost) has become less important in determining transportation demand as incomes have increased, and in that American automobile manufacturers seem to have ceased stressing economy in their advertising. Furthermore, there is no real indication that an electric car with the stated performance can be sold for \$2,000 in the near future.

To see a fortiori whether the advent of electric vehicles might lead to electrical power shortages, the Federal Power Commission** used a very liberal ad hoc estimate of electric vehicle market potential: all second, third, etc. family passenger cars plus 20 percent of the passenger cars owned by all governments, Army personnel residing on base, individuals living in institutions, and cars owned by businesses. With this liberal estimate, they projected 35 million electric cars by 1985, at which time they also projected 85 million internal combustion engine cars—or a few more than the current number.

At the upper end of the spectrum are some exceedingly optimistic estimates by advocates of electric cars. These vary, but usually range from 50% to 90% of the total automobile market by 1990.

Mass Transportation

Possibilities for shifting demand from motor vehicles to mass transportation are examined in detail in Appendix 3. The following points may provide additional perspective:

Mass transportation must be effective at the margin if it is to be effective at all in reducing pollution. It might be effective, for example, if it were to discourage additional one-car families from becoming two-or-more-car families. It might be effective if it were to remain sufficiently attractive and convenient to keep the passengers it now has. And it might be

*The Gallup Report, American Institute of Public Opinion, Princeton, N. J., Jan. 7, 1967.

*C. J. Zwick, "The Demand for Transportation Services in a Growing Economy," RAND Corporation paper P-2682.

effective if its diversion of demand were to be sufficient to reduce peak-hour congestion in some areas and thus reduce the pollution caused by vehicles operating in highly inefficient driving modes.

Mass transportation as now conceived is not likely to be able to do much more. No matter how successful mass transportation is, it will not handle goods, which will continue to be carried mostly by truck. And, perhaps more important, mass transportation, even where it is expanding, is not the only form of transportation being built. New highways and highway improvements are underway or planned in many areas, and no cessation of road construction or improvement appears likely.

In many urban areas, mass transportation now carries an important fraction of people commuting to downtown. The question of interest for air pollution, however, is how many of those not now using mass transportation can be induced or persuaded to shift. For most urban areas, this number appears to be small, relative to the total number of people driving motor vehicles in the area for one reason or another.

With regard to the new San Francisco Bay Area Rapid Transit system, for example, the AAAS Commission on Air Conservation found:* "Roughly 100,000 automobile trips per day are to be diverted to rapid transit. From the viewpoint of coping with traffic and congestion at the hours of most intensive demand, rapid transportation could make an important contribution. From the viewpoint of air pollution control, however, the transit solution, even if it meets the expectations of the Transit District, is only a minor portion of the whole. There are now [1965] about 4 million daily trips in the three-county area, 7 million in the entire Bay Region. These figures [are expected to] rise to 5.2 million and to 11 million, respectively, by 1975. The Transit District estimate that it would carry 258,600 trips per day means that it would absorb only about 5 percent of the passenger travel (in trips, not miles) in the three-county area, and 2.5 percent in the entire Bay Region."

The development of entirely new systems of mass transportation, on the other hand, might drastically change use of public transport. Studies now underway by the Federal Government might provide clues to this question as early as next spring. The impact of such measures, however, is not likely to be felt in less than a decade.

*Reference 5, p. 300.

Reducing Motor Vehicle Travel in Affected Areas

There are three basic ways of reducing motor vehicle travel in affected areas: regulation, pricing, and shifting demand to other modes.

Regulations that have been proposed include:

(a) Banning or regulating the use of internal combustion engine vehicles in affected areas (possibly only at certain times).

(b) Restricting traffic access to major arteries, bridges, tunnels, etc. leading into affected areas (possibly only at certain times).

(c) Reducing the number of parking spaces available for all-day or long-term parking in affected areas.

Pricing policies that have been proposed include:

(d) Instituting graduated, variable tolls on major arteries, bridges, tunnels, etc. leading into affected areas. Such tolls could be adjusted to help control traffic patterns and reduce traffic into affected areas at selected times.

(e) Substantially increasing long-term parking charges in areas used by commuters, while keeping charges relatively low for short-term (less than 4 hours) parking to encourage shopping, social, cultural, and recreational activities.

(f) Indirectly achieving (e) through selective taxation and legislation.

(g) Instituting vehicle use taxes (similar to wage taxes), to be collected from those who use vehicles regularly in affected areas.

Policies for shifting demand to other modes include:

(h) Improving public transportation in affected areas

(i) Making non-polluting vehicles available for inexpensive rental, in conjunction with one or more of (a) through (g).

(j) Making parking spaces more available for all-day parking near collection points for non-polluting modes of transportation ("Park-and-ride").

(k) Improving taxi availability and service, in conjunction with (h) and (j).

The regulations restrict mobility and may reduce pollution at the expense of reducing the activities that attract people into affected areas. Good analysis and study would be needed to assess the regulations' impact.

The pricing policies have attractive aspects, but have the major disadvantages of being somewhat regressive and of working only indirectly to reduce pollution. Reduced motor vehicle travel in affected

areas no doubt leads to reduced pollution; how much reduction is attainable can be determined only through careful experimentation and analysis. Reduced travel also may lead to significant social costs that must be weighed against the pollution gains (although in some areas slightly reduced travel at certain times might reduce congestion enough to be socially beneficial).

Shifting demand to less polluting modes is discussed above and in Appendix 3.

Reducing The Extent Of Driving In Inefficient Modes

There are basically two ways of reducing the amount of driving in inefficient, highly polluting modes: introducing new vehicle configurations and concepts and improving traffic flow.

The former reduces inefficient driving by substituting non- or low-polluting power sources for the internal combustion engine. The main new vehicle configurations and concepts proposed are

(a) Combination of car or truck powered by internal combustion engine with auxiliary transport system to reduce mileage driven—e.g., piggyback, moving pallet, road-rail system.

(b) Combination of short-range electric vehicle with long-range transport system—e.g., piggyback, "third-rail," electronic highways, "Urbmobile."

Improving traffic flow helps reduce pollution because vehicular pollution is created at a rate approximately inversely proportional to speed. An increase in speed from 20 to 30 miles per hour yields about a one-third reduction in pollutants, while a change from 20 to 40 miles per hour brings about a two-fold reduction.¹⁹³ There is considerable room for improvement: Traffic on Manhattan streets during rush hour moves at an average speed of 8½ miles per hour, and on the approach expressways to Manhattan, speeds are as low as 13 miles per hour.¹⁹²

The two basic approaches to improving traffic flow are

(a) reducing traffic levels. Some ways are staggering working hours and encouraging a greater number of persons per individual vehicle.

(b) improving traffic flow at given levels of traffic. Some ways include better traffic control, new expressways, redesigned intersections and traffic bottlenecks, automatic control devices to govern individual vehicles (automated highway), better system labeling.

For suitable types of expressways and highway facilities, controlling vehicle entry at access points

may prevent shock waves and capacity reductions, which in turn lead to increased delays and lowered speeds.* Extending urban expressway systems would tend to help reduce driving in inefficient modes by providing facilities that permit higher performance and vehicle speeds than would otherwise be possible.**

In addition, extending expressway systems would enhance driving conditions for travelers using the more congested local city streets. Much of the traffic now using downtown or central business district streets is made up of travelers who are moving through rather than to or from the downtown area. This through traffic leads to congestion and very low travel speeds for both the through traffic and the local traffic. The through traffic is estimated to range from 30 to 75 percent of the total traffic volume on downtown streets. Consequently, improved travel conditions and improved speeds might stem from the construction of highway facilities designed and located to divert through traffic from local downtown streets.***

Expressway construction is so expensive and takes so long (from inception to completion) that it must be justified on grounds other than air pollution. Its value for reducing pollution also depends, as does the value of the other alternatives in this subsection, on motor vehicle emission characteristics remaining so dependent on average travel speed. If engine modifications were to make emissions relatively independent of the mode of driving, the alternatives in this subsection would have little effect on vehicular pollution.

Reducing Travel By More Highly Polluting Vehicles

Some vehicles emit more pollutants than others. One might thus reduce average emissions per vehicle by reducing the proportion of travel done by more highly polluting vehicles. Policies proposed for accomplishing this include

(a) Imposing taxes or "polluting fees" related to emissions. Emissions might either be measured once a given period in an inspection procedure or be monitored continuously by a pollution meter in each vehicle. Taxes or fees might then be levied on a graduated scale that reflected the relative importance

*Reference 190, pp. 320-326.

**Ibid., pp. 76-82.

***Ibid., pp. 85-87. See also *Public Roads*, 31, No. 4, pp. 92-93; *Public Roads*, 30, No. 9, p. 219.

Usually the percentage ranges upward from 50 percent for large cities and is even higher during peak rush periods.

of the various pollutants and the amounts emitted. This procedure has won the praise of economists because it is similar to normal pricing schemes and seems to be self-enforcing.* Its principal drawback appears to be administrative complexity.

Problems arise mainly because of automobiles' mobility and "because of the great disparity between the number of owners and the number of manufacturers. [Automobiles'] mobility makes it difficult and expensive to meter their use within a particular air shed. A second complication results from the fact that although a number of devices have been suggested, there is at present no inexpensive and reliable method of metering automobile effluents that would be suitable for routine use—for example, as part of an annual inspection. Furthermore, since there are 70,000,000 cars on the roads, but only a handful of manufacturers, the administrative cost of a scheme that deals with manufacturers is likely to be much less than the cost of a scheme that deals with owners."**

(b) Causing polluting vehicles to be operated more efficiently. This might involve checking all cars and trucks for combustion efficiency, training mechanics better to service and maintain pollution-related systems, instituting pollution-inspection procedures, with appropriate penalties for those who fail inspection, and/or developing and placing into operation automated diagnostic centers that quickly, effectively, and inexpensively test the pollution-related performance of all vehicles. These procedures appear quite feasible and should be given serious consideration.

(c) Instilling better driving habits to get more people to follow more efficient driving cycles. Although people generally follow what for them is an "efficient" driving cycle, most drive in ways that significantly increase emissions. Educating the public to drive with less stop-and-go, fewer rapid starts, etc., might yield emission reduction of up to several percent (and increase fuel economy at the same time). Yet, the seeming lack of success of "safe driving" campaigns and of advertising campaigns promoting economy runs, etc., makes a "cleaner air" driving campaign seem hardly worthwhile.

(d) Having motor vehicle taxes increase with in-

creasing vehicle age. The AAAS Air Conservation Commission stated the case as follows:*

Motor vehicle taxes . . . generally decline with the age of the vehicle. They are, on the whole, too low to have much effect either way, but to the extent that they do have an effect, they tend to retard replacement. Yet it is clearly the old "oil burners," with their plumes of blue smoke, that contribute more than their share to air pollution. Motor vehicle taxes should at least remain fixed with age, and preferably rise, thus forcing old cars off the roads sooner. Although some old cars burn fuel more completely than some new ones, . . . statistically age is highly correlated with poor carburetion.

Approximate, preliminary analysis indicates that this tax scheme would affect mainly the disadvantaged and poor, who tend to own older cars, and middle-income families owning two or more cars. In the first case, the taxes would be regressive and would seem unlikely to achieve much of the desired effect. In the second case, the increased tax might stimulate earlier "trading in" of old second cars but would drive off the road primarily cars being used far less than average.

(e) Encouraging use of rented or leased vehicles or taxis. Rented or leased vehicles are usually newer than typical individually owned vehicles, and are often kept in better repair. Taxis are subject through various licensing procedures to government regulation. How to encourage people who do or might drive highly polluting vehicles to rent or lease, or use taxis, is not clear. Study of this question might be fruitful.

Alternatives To Reduce Emissions

The reports of the subpanels on Current Automotive Systems, Energy Storage and Conversion Systems, and Automotive Energy Sources deal with alternatives to reduce emissions. We will thus merely outline these briefly.

There are basically two approaches to emissions control: preventing pollutants from forming and preventing pollutants that are formed from entering the atmosphere. The general classes of alternatives that embody these approaches are:

(a) Devices added to slightly modified internal combustion engines

(b) Basic design changes in the internal combustion engine, coupled with basic changes in the fuel

*E. S. Mills, "Economic Incentives in Air-Pollution Control," in H. Wulgin (Ed.), *The Economics of Air Pollution*, W. W. Norton & Co., New York 1966, p. 48.

**Ibid., p. 48.

*Reference 5, p. 300.

- (c) New propulsion systems
- (d) Hybrid systems incorporating some of both (b) and (c)
- (e) Maintenance and improvement of (a) through (d)

New propulsion systems that use electrical energy entail additional pollution by power generating plants. Power plants using fossil fuels emit sulfur oxides, particulates, and various other pollutants. Nuclear power plants create "thermal pollution" * and radioactive wastes. The additional amounts of these pollutants anticipated at various levels of possible electric car usage are discussed in the Subpanel Report on Automotive Energy Sources.

Because of the large number of motor vehicles affected, consumer costs and benefits associated with emission-reduction steps may be large. For example,

- \$10 per new car in the cost of pollution control amounts to about \$100,000,000 per year for the car-buying public
- \$1 per car for maintenance of emission-reduction systems after all cars are so equipped amounts to approximately \$100,000,000 per year for the car-owning public
- 1 cent per gallon in the cost of gasoline amounts to about \$600,000,000 per year for the car-operating public
- a 1 percent change in gasoline "mileage" amounts to about \$200,000,000 per year for the car-operating public.

Reducing these costs or achieving these benefits thus merits considerable investment.

Verifying emission-reduction, especially on older vehicles, poses a serious problem. Although the new vehicle population can be considered relatively homogeneous, the used vehicle population evidently cannot. Even if a selected sample of older vehicles appears to have "satisfactory" emissions, on the average, there will remain a sizeable likelihood** that average emissions for the total vehicle population will be higher. Sampling procedures rarely obtain adequate samples from the worst maintained parts of the population. And the "average" driving cycle used for testing samples is not likely to account for emission variances caused by congestion (many

cars driving inefficiently at once) and the peak-hour conditions that generate the worst pollution. Some form of inspection for most or all cars is likely to be needed.

Yet, in 1966, only 21 states had safety inspections to which pollution inspection might possibly be added, and only 3 of these (New Jersey, Delaware and the District of Columbia) carried out their inspections with specially trained personnel. To institute emissions checks (at the current measurement state-of-art) might require setting up a new national system. Emissions inspection (although apparently feasible) thus deserves close attention. The concomitant question of emissions measuring devices also deserves high priority; simple, inexpensive, reliable, and accurate devices could greatly simplify the administrative problems of emission verification.

Alternatives to Reduce The Impact Of Emitted Pollutants

There are basically two approaches to reducing the impact of emitted pollutants: reducing atmospheric pollutant concentrations in areas where they may affect people, property, or plants and reducing the impact of the pollutants on the sensitive receptors.

Policies proposed to reduce atmospheric concentrations include

(a) Reducing local concentrations by

(i) Enhancing local atmospheric transport, to disperse pollutants—e.g., enhancing natural micro-meteorological forces by shaping wind patterns (building location and design, major topographical changes, such as building or levelling hills), making best use of the winds available (highway location and design), and reducing the extent of construction (and forest denudation, etc.) favorable to stagnant conditions

(ii) Providing artificial convection

(iii) Preventing pollutants from accumulating in local atmospheres, by "sweeping" with adsorbents, molecular sieves, or reactive catalysts to remove pollutants as they are formed.

The forces involved in (i) are not well understood, but the possibilities appear attractive. Achieving (ii) is likely to be inordinately expensive; the atmosphere ordinarily tends to resist or overcome small-scale disturbances, and even assuming atmospheric cooperation the power and equipment costs involved are enormous. Alternative (iii) involves treating large volumes of air, but may be very attractive and effective in places where air is already collected and

*See, e. g., B. Davidson and R. W. Bradshaw, "Thermal Pollution of Water Systems," *Environmental Science and Technology*, 1, 618-630 (1967).

**Statistically, there is a 50% chance that the population mean will exceed the sample mean, but only a 15% chance that it will exceed it by more than one standard deviation.

pumped as, for example, at tunnel ventilators or garage exhaust vents.

(b) Removing undesirable products from the general atmosphere *

(i) Chemically—react pollutants to form carbon dioxide and water or other less desirable compounds.

(ii) Physically—sweep, scrub, or scavenge pollutants from atmosphere. Enhance precipitation of particulates.

(iii) Biologically—introduce pollution predators, such as microbes or insects.

(i) and (ii) require contacting large volumes of air with other substances. The power needed simply to move the air effectively is likely to be so expensive that these alternatives will be most unattractive except where the air is moved anyway, as in tunnel ventilation.

The problem with (iii) is uncertain ecology. It is difficult to predict what else pollution predators might find appetizing, or what effects they might have on their surrounding biological system. (The "cure" may be worse than the problem.) It also may be difficult to "train" predators to feed only on undesirable substances. Fragrances are due to trace concentrations of complex chemicals not unlike some of those that are considered to be pollutants, and predators might find it difficult to tell the difference. Further, it is difficult to anticipate what mutations might occur and whether the mutations might dominate, and it might be exceedingly difficult to get rid of the predators once they had finished their job.

(c) Blocking the formation of photochemical smog by

(i) Interfering with the offending chemical reactions by introducing inhibitors, removing catalytic agents that favor the reaction, or enhancing more desirable alternate paths.

(ii) Reducing stagnation (i.e., dispersing the key ingredients), or introducing substances that selectively absorb sunlight at especially important wavelengths.

These alternatives are largely speculative. Not enough is known about the chemistry involved to evaluate them scientifically now.

(d) Reducing megalopolitan sprawl.

Through "downwind" and cumulative effects, filling in metropolitan areas is believed to exacerbate

pollution.* Areas that once received relatively clean air receive pollutants from new sources in filled-in areas upwind; these new pollutants compound the older area's existing problems. And pollutants that once were blown quickly out of the megalopolitan convection cells are believed to stay much longer when the megalopolis expands.

Controlling megalopolitan sprawl has proved difficult in the United States. Some European countries (e.g., The Netherlands, Sweden) seem to have had some success, albeit working on a much smaller scale, but it has not proved possible thus far to transplant their approaches into the American context. Research on controlling American "sprawl," of interest for many reasons besides pollution, would seem to be worth pursuing, although benefits from such research (if any) could not even begin to be felt for several decades.

Policies proposed to reduce pollutant impacts include

(a) Locating major highways such that pollution effects on surrounding neighborhoods are kept to a minimum.

(b) Reducing the biological effects of atmospheric pollutants on man by:

(i) Relocating pollutant sources relative to man so that the effective exposure is less

(ii) Designing and distributing protective systems—e.g., gas masks, oxygen, anti-pollutant inoculations

(iii) Making effective diagnosis and treatment of pollution effects readily available

(iv) Developing a means for inducing tolerances and immunities to pollution effects

(i) is likely to become quite important, although the design bases for it are ill-understood. (ii) may become necessary for especially susceptible people (i.e., heart patients, elderly people with respiratory ailments) in high-pollution areas. The need for (iii) and (iv), and the scientific bases on which to develop them, are still unclear.

Impacts Of Pollution Control Policies

Recommendations of this Panel that would result in significant reduction of air pollution are likely to change the pricing, cost, performance characteristics, and accessibility of the transportation system. These

*But see the sensitivity of pollutant concentration to k in Appendix 2.

*The crude model (Model II) developed in Appendix 2 shows average pollutant concentration increasing with increasing urban dimensions. See also Reference 5, pp. 296-298.

changes could result in significant net costs or benefits to society.

The first part of this section concerns the impact of pollution control measures on the disadvantaged and poor. It is included because pollution control policies are likely to affect these groups, and because these effects are easily overlooked. The second part of this section deals with possible impacts of alternative approaches on the national economy.

Impacts On The Disadvantaged And Poor

The poor and disadvantaged (e.g., the old, the young, and the physically disabled) form an increasingly conspicuous proportion of the American population. As part of the public they share the ill effects of vehicular pollution and will share the benefits of its eventual reduction. Yet, because of their disadvantages and poverty, these groups have different perspectives and feel different impacts than the more advantaged segments of the population.

Although the disadvantaged and poor suffer from air pollution, they suffer more from other things. They may value pollution reduction, but they are likely to value more reduction of the disadvantages and poverty that set them apart. Even if pollution reduction is considered solely a form of health care, from which these groups benefit at least as much as the rest of the population,* it is not likely to be one of the forms of health care these groups would most prefer. They may prefer that their money (and everyone else's, in which they share) be spent on health measures that benefit them directly, immediately, and conspicuously. They generally are not now able to obtain health care as good as that available to the more advantaged. Thus, forms of care the advantaged may take for granted may rank far higher for these groups than the "luxury" of reduced pollution.

Moreover, as we have pointed out above, many policies proposed for pollution control might affect taxes or prices in an economically regressive manner, or restrict mobility. Others might add financial burden to that already inherent in owning a car. Still others might make operating older, more poorly maintained vehicles more difficult. Although all of these policies would affect large numbers of people, they might affect the disadvantaged and poor out of proportion to their numbers and to the burden they equitably can bear.

*Because of their largely urban orientation, these groups may benefit proportionately more.

To travel to work, play, shop, or obtain services, except when these are within a few blocks, most Americans tend to use cars or public transit. However, many Americans cannot (or at least prefer not to) obtain cars. They must, therefore, either forego tripmaking, or walk, bicycle, or depend upon public transit which, in most places, meets their needs less and less adequately.

A distinctive characteristic of post-World War II America has been the location of most new employment opportunities farther and farther away from city cores where most of the urban poor live. In the past, the manufacturing, retailing and wholesaling firms which provided work for lower income persons were also in these cores. Since the 1940s, there has been a steady decentralization of these activities, although a centralization of others. A recent Bureau of Labor Statistics study shows that from 1960 to 1965, for example, 62 percent of the new industrial and 52 percent of the commercial construction occurred in the suburbs. (In general, while a large relative decrease in total central city employment has been experienced, absolute employment levels have usually declined little, if at all.)

Between one-fourth and one-half of the urban poor (and a higher proportion of the disadvantaged), varying with areas, income levels and other reasons, do not own or have use of cars. Cars owned by many of the others are usually older, more poorly maintained and therefore less dependable for transportation to work than cars operated by more advantaged Americans.

Any anti-pollution measure which increases the cost or difficulty of maintaining a car inevitably touches the disadvantaged and poor first, thereby further reducing the number of those who have access to autos.

Resorting to public transportation, the poor and disadvantaged without cars often encounter a discouraging situation. Industries and other work places located in suburbs and at the urban fringes are usually poorly served by mass transportation. If service is provided at all, the rider may have to take a complicated route involving several transfers, long travel and high fares. Mass transport lines and routes are designed principally to transport central city commuters to downtown and back home again. Mass transportation's adaption to a different pattern of service needs has been slow, and indeed, may not be possible without public subsidies, changes in the way urban transportation systems operate, or new kinds of technology. The reason for this is that the scatter-

ing of work places in a widely dispersed pattern prevents the generation of large volumes of passengers going from one point to another which are necessary to support it.

Because, in addition, the disadvantaged are frequently unable to drive, pollution control measures that weaken mass transportation's already fragile position may tend to harm the disadvantaged and poor. Measures that expand and strengthen mass transportation, particularly its capacity to serve non-radial and random travel desires, may, on the other hand, be beneficial. (Making taxis cheaper and more available, for example, might greatly benefit the aged and handicapped.)

Measures that increase motor vehicles' initial cost might worsen the situations of the disadvantaged and poor unless improved financing arrangements could be developed to assist with the purchase. Even better financing might not help, since one difficulty these groups often face is qualifying for loans and maintaining payments, especially where high interest charges accompany them. On the other hand, measures that reduced operating costs and maintenance requirements would be likely to benefit these groups greatly. Since they usually purchase used rather than new vehicles, maintenance and operating costs figure prominently in determining whether they can continue to use them.

Measures that increase the complexity of travelling (such as intricate regulations, restricted mobility, and fragmented mass transportation) might disproportionately affect the poor and disadvantaged, who often find travelling difficult now. They are likely to be less able than the more advantaged to cope effectively with measures that require "knowing the system" and are more likely to be defeated or frustrated by policies intended to limit, but not eliminate, pollution-causing travel.

Distributional effects stemming from pollution control policies thus may be quite important. The disadvantaged and poor lack capacity to absorb changes easily. And some of the changes to control pollution may fall on them disproportionately. While the effects produced may not be sufficient cause to discard the policies, they point up a necessity to constrain the policies, and to consider related actions that can ameliorate those consequences deemed harmful or undesirable.

Impact On The National Economy

Pollution control affects not only the transportation system but also products—automobiles, trucks

and motor fuel—that account for a large part of the American gross national product. Major changes resulting from pollution control measures, therefore, could have large impacts on the national economy.

If, to choose an extreme example, electric vehicles were to predominate some decades hence, vast amounts of petroleum now used to make gasoline would have to be converted into other products or be left unrefined or underground. Service stations would have to be converted to handle the new vehicles and their particular requirements. Electrical distribution networks would have to be extended and expanded in heavily populated areas to permit the distribution and use of recharging outlets. Batteries or fuel cells (or other energy conversion devices) would have to be designed to minimize the use and, or facilitate the recovery of scarce or precious materials.

Less extreme, indeed quite foreseeable, is the removal of lead alkyls from gasoline. The impact of this step, assuming no accommodating changes in engine design, has been explored in a recent paper by Lawson, Moore, and Ratner.¹² Because the impact they present has unattractive features, notably considerable expense and a possible shortage of platinum, it may be necessary for automobile and oil companies to cooperate in adapting to any removal of lead. In this regard, as well as others, the joint efforts of Ford Motor Company, Mobil Oil Corporation, Atlantic-Richfield Company, Marathon Oil Company, Standard Oil Company (Ohio), Sun Oil Company, and Standard Oil Company (Indiana), and Chrysler Corporation and Standard Oil Company (New Jersey), on pollution control appear to be very desirable.

Vehicle and fuel modifications to combat pollution might also have significant side benefits for safety. The opportunities presented by basic engine changes should be used also for changes related to safety. And fuel changes to control evaporation may also help reduce the threat of fire and explosion in automobile accidents. (Conversion to non-gasoline powered vehicles would reduce fire losses even more.) It is difficult to assign dollar value to improved safety* and reduced fire hazard, but both could be quite important to the national economy.

UNCERTAINTIES

This section examines uncertainties and explores

*For an initial attempt, see "Application of Benefit-Cost Analysis to Motor Vehicle Accidents," U. S. Department of Health, Education and Welfare, Office of Assistant Secretary for Program Coordination, August 1966.

their possible impacts and policy implications. It contains three subsections, which cover (1) major uncertainties and their implications, (2) additional problems for research, and (3) system experimentation.

Major Uncertainties And Their Implications

Uncertainty, or lack of perfect knowledge, derives from four major sources:

- a. From imperfect ability to predict the future (e.g., uncertainty about future political or strategic contexts, or about future technological state-of-art);
- b. From imperfect ability to predict people's actions or reactions (e.g., uncertainty about competitors, opponents, potential customers);
- c. From lack of time, money, or effort needed to obtain information about planning factors (e.g., uncertainty about the biological effects of nitrogen oxides);
- d. From chance or random elements arising from complexities beyond current understanding or control.

Uncertainties of types (a) and (b) can never be resolved completely, except by the passage of time. Uncertainties of type (c) can be partially resolved by sufficient time, money, and effort, but perfect resolution would be either infinitely expensive or take infinite time. Uncertainties of type (d) can be treated with the mathematical tools for stochastic processes (i.e., processes governed by chance or probabilistic laws), although full treatment is often very difficult.

Uncertainties that cause the most trouble in pollution control are of types (a), (b), and (c). These, and some of type (d), adversely affect our ability to set long-term standards or select long-term pollution-control strategies.

Some of these major uncertainties and their implication are:

(1) **Biological and medical effects of pollutants**—especially effects of long-term exposures to relatively low concentrations (i.e., chronic or cumulative effects).

Many of the constituents of automobile exhaust—carbon monoxide, nitrogen oxides, lead-compound aerosols—are well known industrial hazards. Toxicity standards for industrial exposure have been established for many of them, and progressive companies whose employees contact these chemicals insist upon safety controls and medical monitoring. Knowledge of the effects of moderate-to-low concentrations, especially those which persist for long periods of time, however, is generally unavailable.

In recent testimony before Congress, HEW Secretary John Gardner stated that health authorities are greatly "concerned today with the slow, insidious effects on human lungs of air pollution levels which are [low] but continued every day and year after year. That air pollution does indeed increase the prevalence or severity of chronic respiratory diseases has been stated with more and more certainty by outstanding authorities." * But considerable uncertainty remains, and far more information is needed

Implications: If chronic or cumulative effects resulting from prolonged or repeated exposure to relatively low concentrations of pollutants are important, even if only for certain segments of the population (e.g., young children, pregnant women, elderly people), then pollution standards (for appropriate substances) may have to be exceedingly stringent. Such stringent standards might necessitate pollution-control measures beyond any now envisioned, or might necessitate serious efforts to develop essentially pollution-free vehicles that could be substituted for internal combustion engine cars in areas where pollution is especially severe (e.g., centers of metropolitan areas, junctions of megalopolitan atmospheric convection cells).

(2) **Micrometeorology**—the local atmospheric transport that determines the relations between automobile emissions and local pollutant concentrations.**

Knowledge of small-scale atmospheric convection and diffusion, and of the processes that govern them, is critical in relating automobile emission standards to the biological, physical, and chemical effects of pollutants. Where pollutants are rapidly dispersed, higher emissions can be tolerated; conversely, where local air is stagnant, so that pollutants collect, only very low emission can be accepted.

Implications: Certain streets, areas, and times of day are more susceptible than others to severe atmospheric pollution. Traffic control taking pollution into account thus may be able to reduce the incidence of intolerable concentrations. Similarly, certain building patterns and expressway designs and locations may lead to greater pollution—either on the expressway or in immediately adjacent areas—than others which use or enhance favorable micrometeorology. Since expressways and reorganizations of streets, buildings and topographical features, tend to result in expensive and semi-permanent changes to

*Reference 280, p. 24.

**Meteorologists often prefer to call this level of transport "mesoscale."

metropolitan areas, care should be taken to ensure that pollution incidence is not increased. Improper design (which cannot now be adequately recognized) may offset a considerable part of the pollution reduction gained from automobile engine modification.

Concomitantly, emission standards (notably at low levels) will be difficult to set and enforce without better understanding of relevant micrometeorological processes.

(3) Ultimate limits for internal combustion engine pollution control

Understandably, ultimate emission levels for the internal combustion engine are not now known. Neither is (with any high degree of certainty) the specific technology or technologies that will be needed to attain "ultimate" levels; current approaches may not be adequate.

Also not known are the "ultimate" levels that must be attained—because of the uncertainties concerning biological, aesthetic, and physical effects of pollutants, and the uncertainties of relating exhaust concentrations to concentrations in the air.

Implications: Cost and time projections related to the development of new technologies are notoriously poor. Thus, what now appears to be the optimal course to control motor vehicle air pollution may, with time, appear far less attractive than a host of alternatives. Particularly when the new technology sought is constrained to fit into a preconceived or predetermined complex system, cost and time estimates projected a decade ahead tend to be, almost without exception, highly optimistic.

Also, "ultimate" limits, once attained, may prove too high for some pollutants under some conditions. Dispersion of metropolitan areas, combined with increasing demand for automotive travel (increasing numbers of automobiles and increasing numbers of metro-miles driven per automobile per year), may offset much of the engineering reduction in pollutant emissions. Cumulative exposure may heighten pollutant sensitivities in certain individuals. And, when combined with locally unfavorable meteorology, the emission levels may simply be too high according to the pollution standards then in effect.

(4) Lifetime reliability and performance of current (and projected) pollution-control devices

The reliability and performance of pollution-control vs. time has not been demonstrated adequately. If currently approved devices, and their descendants, deteriorate significantly, effective pollution control may be only a fraction of that now estimated.

Implications: To monitor deterioration and to insure effective pollution control, some form of testing or inspection—either of all cars or of meaningful samples—will be necessary. Thus, quick, inexpensive, and reliable measuring tests and devices will be essential; current tests and devices, although better than their predecessors, are still inadequate for large-scale application. Also, to ensure effective compliance with Federal and State laws relating to motor vehicle air pollution, inspection systems and procedures, and methods of funding, will be needed. Unless advanced methods (e.g., continuous monitoring devices on each car, certified and tamper-proof, that can be read quickly) are developed, such inspection systems may require extensive, expensive series of stations with trained inspectors and complicated equipment.

(5) Suitability criteria—limits of acceptable performance and design characteristics.

Predicting what the public will or will not accept or buy is difficult and perilous, as any venturesome company knows. Studies of "requirements" usually extrapolate what now exists, and surveys usually show that people with money and good judgment want to buy the best of what is available. Unconventional vehicles using modern technology have not been made available to the public, so that conclusions about marketability must remain speculative.

Implications: Pollution-control policies based on the assumption (often implicit) that the public will accept only performance and design characteristics very close to those now offered them are very probably over-conservative. Although large by some measures, by other measures the menu of alternatives currently offered the public is small. Thus, the basis for judgment by extrapolation is small, and the judgments so derived are open to serious question. Innovations need not only displace demand from current alternatives; they can also induce demand that did not exist before, as people find ways to use the innovations' special advantages. Hence, pollution-control alternatives that involve departures from current performance and design characteristics should not be ruled out a priori if they are attractive (at least potentially) by pollution-reduction criteria.

(6) Relations of transportation, particularly automotive transportation, to the metropolitan "system."

Despite considerable analysis, the detailed relations between transportation—particularly automotive transportation—and the rest of the metropolitan system are still unclear. Although transportation clearly

helped to form the shape and character of American metropolitan areas until very recently, it is not clear whether transportation is still a determining force or whether it has become a "dependent variable" responding to other forces. It is also not clear, for example, what the effect would be of greatly improving traffic flow in "downtown"—whether the net increase in average speeds (which would lead to a reduction in pollution) might be offset by a corresponding increase in traffic volume (attracted by the lessened congestion), and by a decrease in the use of public transportation (because public transportation would become comparatively less desirable).

Implications: Because the system is so complex and ill-understood, the net effects of changes cannot be determined from paper studies. Experimentation is absolutely necessary. But to be useful, experimentation must be carefully planned and monitored and the experimental results must be carefully collected and analyzed. Experiments that are not designed carefully rarely yield meaningful information.

Experiments preceded by careful planning—such as the University of Pennsylvania-General Motors electric vehicle study for Philadelphia (sponsored by the Department of Housing and Urban Development)—would appear to be fruitful. Further, similar efforts should definitely be encouraged.

Furthermore, because metropolitan areas are complex and not all identical, it is not immediately obvious what current conditions may properly be assumed as constraints for future development. The more constraints imposed on technological development, the more difficult that development becomes. Demanding optimal performance in the current environment of pollution-control technology that will operate some decades hence is unrealistic.

But, because of the long times required for effective development, it does not seem feasible to postpone selection of development policies until all uncertainties are resolved. The logical, practical course is one of sequential decisionmaking: choosing alternative paths to be pursued in parallel, preserving as much freedom of choice as possible until specific decisions must be made, and bringing new developments to test as early as possible at each stage of the development program.

Additional Problems For Research

The following thus appear to offer challenging and important problems for research:

a. Meteorology and micro-meteorology, especially as they relate to air pollution, and to motor vehicle

air pollution in particular.

b. Chronic and cumulative effects of pollutants, especially those effects that may not become noticeable until they are so advanced that they are difficult to treat.

c. Biological effects of lead from motor gasolines, and biological effects of nitrogen oxides.

d. Implications of new propulsion systems for city design and system management.

e. Probable interactions between vehicles having new propulsion systems and current cars, especially with regard to possible crashes and passenger safety.

f. Control systems for automated highways, to improve driving efficiency and safety.

g. Methods of monitoring experiments, programs, and forecasts to collect information that can improve future planning and projections.

h. New systems of urban transportation which combine the best features of automotive transport and mass transit.

Other important problems for research are described in context throughout this report.

System Experimentation

It is frustrating to have to say in nearly every section "not enough is known." To improve this situation, in the virtual absence of suitable theoretical foundations, one must conduct experiments. Experimental projects, properly framed, can uncover a lot of answers of the kind likely never to be gained through context-free analysis. For some of the problems and uncertainties, only an experimental approach offers much hope of yielding useful results.

In considering people's preferences, with regard to an inner-city circulation system using electric vehicles, for example, any number of plausible hypotheses can be advanced. Current knowledge permits little penetration. Thus, to overcome this impasse, one has to try, to see how a live system reacts. The joint University of Pennsylvania-General Motors project mentioned above has plans to do just that: to formulate tentative hypotheses and test them carefully in real situations. Whether or not it succeeds, similar endeavors should be strongly encouraged.

We want to distinguish carefully between systematic experimentation and both case studies and "experimental demonstrations." Case studies have tended to be passive descriptions of the past or near past, and have generally resembled experiments only insofar as they have worked with "real" data and people. Only rarely have they attempted to perturb

the system under study and observe its response; only rarely have they constructed experimental designs that required becoming actively involved in the processes being studied.

Experimental demonstrations, on the other hand, have tended to the other extreme. As usually practiced in transportation, they have involved the introduction of a new system or partial system into an unstudied, unprepared, unplanned context. Many things have been changed simultaneously, and few have been measured. Thus, it has rarely been possible to disentangle the half-measured results to see what might have led to what, or what might have happened if . . . Too often, the results have been totally obscured by ostensibly minor failures or breakdowns

that have led to apparent failures of the overall system.

Experiments in the sciences and engineering have a rather different orientation, which we wish to see exploited. Even when, as in complex technological systems, underlying processes are not well understood and conditions may not be reproducible, systematic planning, careful design, and thoughtful measurement often lead to useful results. The methods of experimental design, system identification, and selective confounding of variables have enabled considerable practical understanding of complex systems to be acquired. With suitable modifications, they might be nearly as useful for treating systems of interest in combating vehicular pollution.

Appendix 1

Model I: Relating The Total Rate Of Vehicular Emissions To Driving Activity And Vehicle Characteristics

Pollution Per Vehicle

Different aspects of driving produce different amounts of pollution. Let us list the various pollutants of interest and designate the j^{th} one on the list ($j = 1, 2, 3, \dots$) by the subscript j . Let us also list the various distinguishable aspects of driving, and designate the k^{th} one on this list by the additional subscript k . Now let us represent the emission characteristics of a particular vehicle by the symbol A_{jk} , the amount of pollutant j emitted per "unit" of driving aspect k . The unit might be miles for steady driving in a particular speed range, time for idling, or numbers of times for acceleration and deceleration - whatever is technically meaningful to relate pollution to the kind of driving done.

Let us represent the extent of driving (i.e., the number of units) in driving aspect k by D_k . Since for policy it may be useful to identify the location and time of the driving, let us expand the representation of driving to $D_k(R, T)$, the extent of driving in aspect k done in region R during time period T .

Then the quantity of pollutant j emitted by a vehicle in region R during time period T , $Q_j(R, T)$, is found by adding the amounts produced in each aspect of the driving cycle:

$$Q_j(R, T) = \sum_k A_{jk} D_k(R, T). \quad (E 1)$$

The Vehicle Population

For policy, it is useful to distinguish among vehicles

of different ages and types. Vehicles produced in different years have had different initial emission characteristics, especially in the years since California and Federal emission standards were instituted. We expect, further, that initial emission characteristics will continue to change as the research now in progress (and the research to come) bears fruit. In addition, it appears that emission characteristics change as vehicles age. The rate of this change may depend upon the kind of emission control used initially (i.e., how susceptible it is to deterioration) and upon the maintenance the vehicle receives as it is used. The type of vehicle is important, of course, because vehicles with different engines will have different emission characteristics (types may be differentiated in any way that is meaningful and useful.)

Let us list all the relevant types of vehicles, and denote the m^{th} one on the list by the additional subscript m . Let us denote the year of interest (e.g., 1980) by y , and the age of a given vehicle (in years) by a . A vehicle a years old in year y is said to have been produced in $y - (y - y - a)$. In the year of interest, denote the number of vehicles a years old of type m by $N_m(y, a)$. If the fraction of vehicles of type m surviving a years is $S_m(a)$,* and the number of

*Values of $S(a)$ for the total automobile population are given in the two right-hand columns of Table 48. Values for trucks (undifferentiated by type) can be derived from data in *Automobile Facts and Figures*. More useful, detailed values undoubtedly exist in automotive company files.

type m originally produced in y_0 is $N_m(y_0)$, then

$$N_m(y, a) = N_m(y_0) S_m(a). \quad (\text{E-2})$$

The different types of vehicles (e.g., small cars, medium-displacement cars, large cars, small trucks, large trucks, buses) have different emission characteristics and are used and driven in different ways. The emission characteristics further depend on the year the vehicle was manufactured and its age in the year of interest. Age probably also influences the way the vehicle is used. Let us represent these dependencies by redesignating $A_{j,k}$ as $A_{j,k,m}(y, a)$, $D_k(R, T)$ as $D_{k,m}(R, T, a)$, and $Q_j(R, T)$ as $Q_{j,m}(R, T, y, a)$. Equation (E-1) then becomes

$$Q_{j,m}(R, T, y, a) = \sum_k A_{j,k,m}(y, a) D_{k,m}(R, T, a). \quad (\text{E-3})$$

Emission Characteristics

For evaluating policies, it is useful further to resolve the factors affecting emission characteristics. Each type of vehicle when originally produced has emission characteristics denoted by $A_{j,k,m}(y_0, 0)$ —i.e., $A_{j,k,m}$ for a vehicle 0 years old in year y_0 . The initial "effectiveness" of pollution control for new vehicles then can be represented in the form

$$E_{j,k,m}(y_0, 0) = \frac{U_{j,k,m} - A_{j,k,m}(y_0, 0)}{U_{j,k,m}}. \quad (\text{E-4})$$

Here $U_{j,k,m}$ represents the amount of pollutant j emitted in driving aspect k by a vehicle of type m having no pollution control—i.e., $U_{j,k,m}$ represents the uncontrolled emissions. If pollution control were to be ineffective, that is, if $A_{j,k,m} = U_{j,k,m}$, then $E_{j,k,m}$ would be 0. If pollution control were to be totally effective, i.e., if $A_{j,k,m}$ were to become zero, then $E_{j,k,m}$ would be 1.

Let us now denote the change of effectiveness with vehicle aging (and maintenance) by

$$E_{j,k,m}(y, a; M) = E_{j,k,m}(y_0, 0) f_{j,k,m}(a, M). \quad (\text{E-5})$$

Here $f_{j,k,m}(a, M)$ denotes the manner in which degradation (or improvement) of pollution-control effectiveness varies with vehicle age and maintenance policy (M). The emission characteristics in year y for vehicles of age a then are given by

$$A_{j,k,m}(y, a) = A_{j,k,m}(y_0, 0) \left[\frac{1 - E_{j,k,m}(y, a; M)}{1 - E_{j,k,m}(y_0, 0)} \right]. \quad (\text{E-6})$$

Total Emissions

The total emission in region R during T from vehicles of type m , $Q_{j,m}(R, T, y)$, then is given by adding the contributions from type m vehicles of all ages

$$Q_{j,m}(R, T, y) = \sum_a Q_{j,m}(R, T, y, a) N_m(y, a). \quad (\text{E-7})$$

Adding the contributions from vehicles of all types gives the total quantity of pollutant j emitted in region R during time period T in year y , which we denote by $Q_j(R, T, y)$:

$$Q_j(R, T, y) = \sum_m Q_{j,m}(R, T, y). \quad (\text{E-8})$$

Combining equations (E-5), (E-6), (E-3), (E-2), (E-7), and (E-8) then yields a relatively straightforward model that relates substantive, measurable quantities—and the policies affecting them—to the rate of pollutant emission. This simple model can be ramified as necessary.

The above formulation assumes that all numbers are exactly known. In fact, many of the quantities are uncertain—because they are inherently statistical or subject to random fluctuations, or because they are estimates derived from projections and "best guesses." These uncertain quantities properly should be represented by probabilities. Making the model probabilistic is straightforward (but lengthy), so that we will not carry out the extension here.

Appendix 2

Model II: Relating Atmospheric Pollutant Concentrations To Emission Rates, Urban Sprawl, And Atmospheric Properties

Assumptions: Steady-State model, with

(1) Constant wind velocity (magnitude and direction). Wind patterns and speeds clearly do change, and these changes are critical in determining pollution severity. Yet, assuming constant wind velocity

permits simple analysis of the model and offers an intuitive feeling for the general importance of the wind.

(2) Constant, isotropic atmospheric diffusivity. A serious assumption, but dispersion plays a minor role in this model, in any case.

(3) Constant emission rate. A transient model incorporating fluctuations in emission rate is easy to develop by extending this one. Assuming emissions constant over time simplifies analysis somewhat, yet does not alter emissions' basic role.

(4) Pollutant j removed at a rate proportional to its concentration. Dissolution (e.g., Henry's Law) and chemical reaction (first-order or pseudo-first-order reaction) may be approximately represented by this relation. The rate does not seem likely to be independent of concentration, and any other proportionality complicates analysis.

(5) Perfect vertical mixing, so that the concentration is uniform with altitude in the "participating" part of the atmosphere. This assumption is clearly unrealistic. Adding a vertical gradient would not alter the model's basic results, however, and would make the results less easily interpretable.

(6) Urban area (region of emission) embedded in an essentially infinite, source-free environment. If the urban area of interest is not surrounded by clean air, we need only redefine the area to include upwind sources, and then look at the part of the region that interests us.

Governing Equation: Diffusion equation with emission source

(a) x -axis defined to be the direction of the wind

$$(b) -D \left(\frac{\partial^2 c}{\partial X^2} + \frac{\partial^2 c}{\partial y^2} \right) + V \frac{\partial c}{\partial X} + kc = S(X, y) \text{ for pollutant } j$$

Dispersion + Convection + removal = emission source

(c) Boundary conditions:

$$c \rightarrow 0 \text{ as } X \rightarrow \pm \infty, \quad y \rightarrow \pm \infty$$

This equation can be solved easily, but its solution can be difficult to interpret simply. Further assume, then, that emissions are uniform in the direction perpendicular to the wind, i.e., that $S(X, y)$ is uniform in y . Then the equation becomes

$$(d) -D \frac{d^2 c}{dX^2} + V \frac{dc}{dX} + kc = S(X),$$

$$c \rightarrow 0 \text{ as } X \rightarrow \pm \infty$$

Solution

The solution to equation (d) is

$$c(X) = \int_{-\infty}^{\infty} G(X, u) S(u) du,$$

where

$$G(X, u) = \frac{1}{R} [\exp(L_1(X-u))H(u-X) + \exp(L_2(X-u))H(X-u)],$$

$$H(x-u) = \begin{cases} 1 & \text{when } x \geq u \\ 0 & \text{when } x < u \end{cases}$$

$$R = (V^2 + 4kD)^{1/2}$$

$$L_1 = \frac{1}{2D}(V+R), \quad L_2 = \frac{1}{2D}(V-R)$$

$S(u)$ represents the pattern of emissions.

The solution is simplest if emissions are taken to be uniform within the urban area (at level S) and zero outside. To examine the solution closely, we must have an idea how large the key dimensionless groups are. These are

$$\frac{kd}{V} \text{ and } \frac{kD}{V^2}.$$

Matching this simple solution against observed concentrations, emission rates, etc., we find relatively good agreement for $k \sim 1/\text{day}$, which seems physically reasonable, too; for an urban area 5 miles across with a wind of 10 mph, then

$$\frac{kd}{V} \sim \frac{1}{48} \sim 0.02$$

For a diffusivity of 10 ft²/sec (probably much too large),

$$\frac{kD}{V^2} \sim 5 \times 10^{-7}.$$

Then, to a very good degree of approximation, for the urban area ($0 \leq X \leq d$),

$$C(z) \cong \frac{S}{k} \left\{ \left[1 - \exp\left(-\frac{kd}{V}z\right) \right] \text{ pure convective solution} + \left(\frac{kD}{V^2} \right) \left[1 - \exp\left(-\frac{Vd}{D}(1-z)\right) \right] \right\},$$

First-order Term
for Dispersion

where $z = x/d$ is a dimensionless distance. Integrating with respect to z gives the spatial-average concentration

$$C \cong \frac{S}{k} \left[1 - \left(\frac{V}{kd} \right) \left(1 - \exp\left(-\frac{kD}{V}\right) \right) + \frac{kD}{V^2} \right]$$

(The exponential expression in the dispersion term is negligible.)

Taking partial derivatives then yields the sensitivity of the average concentration to each of the variables.

It is interesting to note that for small values of (kd/V) ,

$$C(z) \approx \frac{Sd}{V} z \left(1 - \frac{1}{2} \frac{kd}{V} z + \dots \right),$$

which makes the sensitivities clear.

Appendix 3

Shifting Demand To Mass Transportation

Although patronage of transit systems has declined in recent decades, public policies may be capable of checking (and in some cases of reversing) this trend; however, it does not appear that these changes can be accomplished at low cost. Where transit may be successful in attracting riders in large numbers, reductions in air pollution may be measurable.

Trends In Use Of Transit

The automobile has assumed a central position in urban transportation. Offering convenience, flexibility and privacy, it has not only attracted most of the new travellers, but also made strong inroads into transit's traditional markets. Despite phenomenal urban population growth in the 1950's and 60's, patronage of transit declined from 12.9 billion revenue passengers in 1951 to 7.2 billion ten years later. Many companies went out of business. Average annual profits nationally shrank from 4.6 per cent to 1.4 per cent of revenue.

The competition of the automobile was felt particularly hard during the "off-peak" hours, those times of the day other than the two hours in the morning and another two in the afternoon when most commuters go to and from work. As relatively high levels of commuter service were utilized for only about 20 hours a week, with much of the equipment and labor lying idle the rest of the time as off-peak patronage declined, transit found its profits decreasing or experienced deficits. To meet these situations, companies turned to large fare increases. On the Consumer Price Index, transit fares doubled between 1950 and 1963, compared to a rise of only 25 per cent in general or automobile cost levels. These fare increases accelerated the displacement of transit by the automobile, though probably not to a significant degree.

The increasingly dispersed urban living and occupational locations which the automobile helped bring

about also hurt transit, particularly in terms of providing service to new urban dwellers and new business areas. Traditional transit modes such as commuter railroads, streetcars and subways depended upon high population concentrations and riders who wanted to travel from a few origins to a few destinations at the same time. Even buses, which are more flexible, had difficulty in realigning their operations to provide attractive and economical service to passengers who wanted to depart from and arrive at many different locations.

The Potential For Improving Transit's Attractiveness

Several schools of thought have arisen about the function and future need for transit in urban areas. What seems clear from these, in spite of their differences, is that

—Transit will continue to exist in most urban areas because it fulfills certain vital functions which cannot be performed as satisfactorily by the automobile or other existing modes, and

—Transit can be made more attractive to potential riders by infusions of new public policies, operating techniques and technology that will lead to markedly improved door-to-door service.

In recognition of these main points of consensus, many cities and states in recent years have created public bodies to own, operate or stimulate improvement of transit systems. In addition, the Federal Government initiated an Urban Mass Transportation program in 1961, assigned to the Department of Housing and Urban Development, which has grown to encompass a spectrum of research, demonstration, planning and capital assistance, and manpower training activities.

Assisted by Federal financial aid, a number of urban areas have invested in new equipment, improved stations and stops, constructed park-and-ride facilities, and have experimented with new techniques for providing service and managing transit

operations. Such actions have sometimes reversed or at least halted downward patronage trends.

Mass transit by its very nature was unable to offer the schedule time and route flexibility of the automobile. Nor could it provide certain psychological satisfactions such as privacy and the feeling of personal control over one's environment which the auto offers. What it has been able to provide in some instances is time and cost savings, the latter usually in terms of traveler out-of-pocket expenses.

Total time savings appear to be particularly important in inducing people to use one or another mode of transport. When transit is convenient, frequent and rapid, it may provide substantial door-to-door time savings over the automobile, especially to riders with destinations where parking is inconvenient or scarce, or there is a high density of activity.

Possible Future Directions In Transit

The Federal Government is currently committed to improvement of urban transit. Moreover, in a 1966 amendment of the Urban Mass Transportation Act, the Congress directed the Department of Housing and Urban Development to submit a long-range program proposal to the President and the Congress not later than March, 1968, which will bring into being "new systems" of urban transportation. HUD is engaged now in a number of urban transportation studies, on which approximately \$3.5 million is being expended.

Within the newly created Department of Transportation, the Federal Highway Administration (which encompasses the Bureau of Public Roads) and the Federal Railroad Administration are both carrying forward research activity which may contribute to improvement of urban transit.

It seems safe to assume that higher priority will be given to improvement of traffic flow for transit vehicles on urban streets and freeways, and that this will result in higher performance local and express buses offering considerably improved service. Where transit systems in recent years have begun to operate express-type services, there has usually been a favorable public response.

In the past, most highway designers and traffic engineers have tended to assign all vehicles equal weight and to maximize total vehicle movement. This emphasis tends to encourage automobile use and ignores the question of whether different kinds of vehicles confer different benefits at different times of the day. An alternative traffic control approach might be adopted which would change the mix of

vehicles in the traffic stream during peak commuting hours. The proportion of buses would be increased in the traffic stream and both auto and bus average speeds could rise substantially. Although this might lead to small delays for automobiles waiting to enter the faster moving facility, there is also the possibility that, with the performance of buses enhanced, a large number of current auto users would switch to transit and free the road for others who continued to use cars. Studies which explore this possibility would be desirable.

High priority in the near term should also be given to steps which provide tighter linkages between the automobile and transit, so that the advantages of each mode can be put to best use. Provision of ample parking space has been one of the contributing factors in attracting former auto commuters to transit for part of their trip. It has allowed them to use their cars for movement in the dispersed suburban residential area, but has encouraged use of transit to traverse more congested or densely populated areas. (Such parking space is not costless, and represents a subsidy that must be weighed against the benefits it yields.)

Although park-and-ride facilities have become more common, they are still relatively few and far between. Almost none exist to provide links between auto and express bus services. Public policies can alter this situation.

Business district fringe parking, tied in with convenient shuttle transit which connects the parking lots to the business area and also provides quick and attractive circulation with the area, is a similar measure which could be brought into being in many urban areas.

These and similar changes in traffic management deserve serious study, since they apparently offer other potential benefits to urban transportation. From the standpoint of pollution control, their effect should be to reduce the net amount of pollutant per traveller per mile or minute of travel, without increasing the price to him of using the transportation system. Indeed, a shift to transit should lower the individual's total out-of-pocket transportation cost for a given unit of travel.

On the horizon are possible technological changes in urban transit. Of particular interest are those concepts which modify the automobile to give it characteristics of a transit vehicle.

The **Urbmobile** concept envisions a small, limited performance car-type vehicle which can operate both on regular city streets and on special high-speed,

automatic "guideways." On the street it is under the driver's control and has a fairly low top speed. When it enters the guideway, a central source of control and power takes over, so that high speeds and close spacing can be attained. Such vehicles might be privately owned, but might also be merely paid for during use, in which case the local operator of the guideway system would own them.

Since the concept does not require high performance capability off the guideway, an urbmobile would not need high power or energy capacity. Assuming the overall system concept has merit, it should be possible to develop adequate power sources for such low-emission vehicles within a relatively short time.

An alternative concept involves a piggy-back approach. Automobiles, small buses, and even passenger pods would ride on pallets which move at high speed under computer control on a specially designed guideway. During the ride it would not be necessary for the vehicle's engine to operate.

Conclusions

The feasibility of attracting a higher proportion of travellers to transit needs to be demonstrated and analyzed more carefully. There may be some (though apparently not major) advantages to pollution control in encouraging such diversion, aside from other advantages which increased transit use may have for

urban areas.

Transit itself contributes little quantitatively to air pollution, although what it does contribute is often conspicuous. Most rail transit is electric. Diesel powered buses emit certain undesirable pollutants, but on a per passenger-mile basis these are only a fraction of automobile pollution, as annoying as they often are to those near buses in traffic. Noise and odor have not been overcome, but development and adoption of less- or non-polluting power sources for buses may be easier than the corresponding task for automobiles.

The Federal and many local governments have already begun to undertake transit improvement programs. Acceleration of these to obtain quicker results appears to be desirable.

Achievement of traffic improvement measures, which provide incentives for increased transit use and closer auto-transit linkages where they are appropriate, depends less upon increased Federal funding than upon policy refinements. What is needed from the Federal government, in joint action by the Department of Housing and Urban Development and the Department of Transportation is a clear policy expression of the importance of traffic and highway design measures, and a shift in research and demonstration priorities, to obtain knowledge more rapidly about the appropriate use, costs and benefits of these measures.

Bibliography

1. AGARWAL, PAUL D. and I. M. LEVY. "A High Performance AC Electric Drive System." Society of Automotive Engineers. Paper No. 670178, Automotive Engineering Congress and Exposition, Detroit, Mich., Jan. 9-10, 1967, 10 p.
2. AIR POLLUTION CONTROL DEPARTMENT, County of Los Angeles. "Air Pollution Data for Los Angeles County." Jan. 1967.
3. ALMAULA, B. C. "High Power Ground Applications." Proceedings, 17th Annual Power Sources Conference, May 21-23, 1963, pp. 82-84.
4. ALTMAN, MANFRED. "The Electric Automobile—A Discussion of Strategy, Tactics, and Leadership." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967, 10 p.
5. AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. Air Conservation Commission. "Air Conservation." Washington; American Association for the Advancement of Science, Publication No. 80, 1965, 335 p.
6. AMERICAN INSTITUTE OF PUBLIC OPINION. "Millions of Americans Interested in Electric Auto." *The Gallup Report*, Princeton, N. J., Jan. 7, 1967.
7. ASH, DAVID. "On a Clear Day You Will See the Electric Car." *New York Times Magazine*, pp. 22, 74-78, Jan. 29, 1967.
8. AUTOMOBILE MANUFACTURERS ASSOCIATION, INC. "1965 Automobile Facts and Figures." Detroit, Michigan.
9. AUTOMOBILE MANUFACTURERS ASSOCIATION, INC. "1967 Automobile Facts and Figures." Detroit, Mich. 39 p.
10. "BACKGROUND MATERIAL FOR THE STUDY OF THE NATIONAL SPACE POWER PROGRAM." Volume III, Oct. 1964. (AD 451066).

11. BARAK, M. "Developments in Electrochemical Energy-Conversion Devices, Batteries and Fuel Cells." Institute of Electrical Engineers. Proceedings, 112 (6):1439-1448, July 1965.
12. BARAK, M. "Fuel Cells—Present Position and Outstanding Problems." *Advanced Energy Conversion*, Vol. 6, pp. 29-55, 1966.
13. BARTHOLOMEW, E. "Gasoline Engines." U.S. Patent No. 3,282,261, Nov. 1, 1966.
14. BARTHOLOMEW, EARL. "Four Decades of Engine-Fuel Technology Forecast Future Advances." Society of Automotive Engineers, Inc. Paper No. 660771. National Fuels and Lubricants Meeting, November 2, 1966, 30 p.
15. BARTHOLOMEW, EARL. "Potentialities of Emission Reduction by Design of Induction Systems." Society of Automotive Engineers, Inc. Automotive Engineering Congress, Detroit, Mich., Jan. 10-14, 1966, 18p.
16. BARTOSH, S. J., J. M. McDONAGH, and W. G. TASCHEK. "Fifth Status Report on Fuel Cells." U.S. Army Electronics Command, Electronic Components Laboratory, Fort Monmouth, N. J., June 1965, 200p. (AD 620 114).
17. BARTOSH, STEPHEN J. "500-Watt Indirect Hydrocarbon System." Proceedings, 20th Power Sources Conference, Atlantic City, N. J., May 24-26, 1966, pp. 31-35.
18. BATTAN, LOUIS J. "The Unclean Sky; A Meteorologist Looks at Air Pollution." Anchor Books, Garden City, N. Y., 1966, 141 p.
19. BERMAN, BARUCH. "Selection Guide for Variable-Speed DC Drive." *Product Engineering*, 33:58-67, Apr. 2, 1962.
20. BEUCHL, ARTHUR M. "Technology and the Pollution Problem." General Electric Co., Research and Development Center, Schenectady, N. Y., 1966, 8 p.
21. BINTZ, L. J. "Air Pollution Control System for Internal Combustion Engine." U.S. Patent No. 3,287,899, Nov. 29, 1966.
22. BOCH, H. S. "Control of Automotive Exhaust Gases." U.S. Patent No. 3,074,391, Jan. 22, 1963.
23. BLOIS, STANLEY O. "Electric Car Sales and the Electric Utility." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967, 8 p.
24. BLOOMFIELD, J. "Catalytic Afterburner for Internal Combustion Engines and the Like." U.S. Patent No. 3,220,179, Nov. 30, 1965.
25. BLUM, E. H. "Engineering and Public Affairs: Some Directions for Education and Research." Transactions of the New York Academy of Sciences, April 1967. (The RAND Corporation No. P-3628).
26. BONGARTZ, ROY. "It Clicks, It Hums—It's Supercar." *Saturday Evening Post*, 240:38-40, Jan. 28, 1967.
27. BOOZ-ALLEN APPLIED RESEARCH INC. "Analysis of Functions of Transportation; a Conceptual Framework." Bethesda, Md., June 1966, 536 p. (PB 173 419)
28. BOUCHARD, C. L. "Engine Intake Manifold Air Driven Compressor." U.S. Patent No. 3,299,629, Jan. 24, 1967.
29. BOWIE, H. H. "A Study and Review of Hot-Air Engines." U.S. Army. Office of Ordnance Research, Report No. TM 54-1, April 1954. (AD 45429)
30. BOYD, C. "Method and Device for Exhaust Gas Purification." U.S. Patent No. 3,306,034, Feb. 28, 1967.
31. BOYD, P. G. "Congestion May Revive the Battery Car." *Engineering*, 190:178-179, Aug. 5, 1960.
32. BRICE, ROBERT M. and JOSEPH F. ROSEFER. "The Exposure to Carbon Monoxide of Occupants of Vehicles Moving in Heavy Traffic." *Journal of the Air Pollution Control Association*, November, 1966, pp. 597-600.
33. BROWN, CLINTON E. "Gilled Systems for Hydrospace." *Naval Engineers Journal*, 78:972-976, Dec. 1966.
34. BUELL, et. al. "Lung Cancer in Los Angeles Type Air Pollution: A Prospective Study." *Cancer*, 1967.
35. CALANDRA, J. C. "Lead in the Environment." Lead Industries Association, Inc., 38th Annual Meeting, St. Louis, Mo., Mar. 31-Apr. 1, 1966, 6 p.
36. CALIFORNIA DEPARTMENT OF PUBLIC HEALTH. "Lead in the Environment and Its Effects on Humans." Berkeley, Calif., March 1967, 84 p.
37. CALIFORNIA DEPARTMENT OF PUBLIC HEALTH. "Technical Report of California Standards for Ambient Air Quality and Motor Vehicle Exhaust." Berkeley, Calif., 1959, 135 p.
38. CALIFORNIA DEPARTMENT OF PUBLIC HEALTH. Bureau of Air Sanitation. "The Oxides of Nitrogen in Air Pollution." Berkeley, Calif., Jan. 1966.
39. CAMBELL, ALI BULENT, et. al. "Energy R&D and National Progress." Prepared for the Interdepartmental Energy Study by the Energy Study Group, Washington, U. S. Government Printing Office, 1965, 437 p.
40. CAMBELL, ALI BULENT, et. al. "Energy R&D and National Progress: Findings and Conclusions." An Interdepartmental Study, Washington, U.S. Government Printing Office, 1966, 18 p.
41. CATRON, M. "Forecasting Technology." *International Science and Technology*, No. 69, pp. 83-92, September 1967.
42. CHANDLER, J. M., J. H. STRUCK, and W. J. VOORHEIS. "The Ford Approach to Exhaust Emission Control." Society of Automotive Engineers. Paper No. 660163, Automotive Engineering Congress, Detroit, Mich., Jan. 10-14, 1966, 21 p.
43. "CHEMISTRY AND THE ATMOSPHERE." *Chemical and Engineering News*, 44(13):1A-54A, March 28, 1966.
44. CHOPEY, NICHOLAS P. "What You Should Know About Fuel Cells." *Chemical Engineering*, 71(11): 125-130, May 25, 1964.
45. CHRYSLER CORPORATION. Engineering Office. "History of Chrysler Corporation Gas Turbine Vehicles, March 1954-June 1966; A Review of Gas Turbine-Powered Vehicles Shown Publicly by Chrysler Corporation." Dearborn, Mich., August 1966, 42 p.
46. CHRYSLER CORPORATION. Press Information Service. Press Release, April 12, 1966, 6 p.
47. CLARKE, A. C. "Profiles of the Future." Harper & Row, New York, New York, 1963.
48. COHN, ERNST M. "An Introduction to Fuel Cells." Washington, National Aeronautics and Space Administration, 1967, 11 p. Unpublished.
49. COHN, ERNST M. "NASA Work on High-Energy-Density Electrochemical Power Devices." Washington, National Aeronautics and Space Administration, 1967, 9 p. Unpublished.
50. COHN, ERNEST M. "Terrestrial Applications of Electrochemical Space Power Research." Third Annual Meeting of the American Institute of Aeronautics and Astronautics. Paper No. 66-1012, Boston, Mass., Nov. 29-Dec. 2, 1966, 7 p.
51. COHN, ERNEST M. "The Growth of Fuel-Cell Sys-

- tems." Washington: National Aeronautics and Space Administration, 1967. 15 p. Unpublished.
52. CONWAY, BRIAN E. "Fundamental Battery Research Needed." *Electrical World*, 155:61-63, Feb. 13, 1961.
 53. COOK, W. E. "Apparatus for Preventing Discharge of Contaminants From an Automotive Vehicle." U. S. Patent No. 3,119,231. Jan. 28, 1964.
 54. COOPER, V. R. "Power Plants for Electric Terrestrial Vehicles." Third Annual Meeting of the American Institute of Aeronautics and Astronautics, Paper No. 66-980, Boston, Mass., Nov. 29-Dec. 2, 1966. 3 p.
 55. CORNELL, JACK J. "Passenger Car Fuel Economy Characteristics on Modern Superhighways." Society of Automotive Engineers, Paper No. 650862, National Fuels and Lubricants Meeting, Tulsa, Okla., Nov. 2-4, 1965. 5 p.
 56. COZZENS, BRADLEY. "Electric Utility Associations Promote the Electric Automobile." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 10 p.
 57. CURTIS, ANTHONY. "The Magnetism of Electricity." *Mutator*, pp. 15-19, December 10, 1966.
 58. DAVIDSON, B. and R. W. BRADSHAW. "Thermal Pollution of Water Systems." *Environmental Science and Technology*, 1:618-630, 1967.
 59. DAVIDSON, C. "Steam Road Vehicles—the Forerunners of Motor Cars." London England; Her Majesty's Stationery Office, 1959.
 60. DECLAIRE, G. and A. H. BELL. "Chrysler's Gas Turbine Car; Laboratory Procedures and Development Methods." Society of Automotive Engineers, Paper No. 777D, Automotive Engineering Congress and Exposition, Detroit, Mich., Jan. 13-17, 1964. 27 p.
 61. DEZUBAY, E. A. "High Temperature Fuel Cells." Society of Automotive Engineers, Paper No. 159E, SAE National Aeronautic Meeting, New York, N.Y., Apr. 5-8, 1960. 26 p.
 62. DIETRICH, HOWARD H.; CLARENCE J. ECKERT, and FRED G. MICHAELS. "Mechanism for Reducing Unburned Hydrocarbon Emission." U.S. Patent No. 3,252,450, May 24, 1966.
 63. DOLZA, J. "Engine Induction Means." U.S. Patent No. 2,821,181, Jan. 28, 1958.
 64. DOLZA, JOHN. "System for Reducing the Emission of Unburned Combustibles From an Internal Combustion Engine." U.S. Patent No. 3,192,706, July 6, 1965.
 65. DOOLEY, JAMES L. and ALLAN F. BELL. "Description of a Modern Automotive Steam Powerplant." Society of Automotive Engineers, Paper No. S338, Los Angeles Section Meeting, Jan. 22, 1962. 14 p.
 66. DORF, RICHARD C. "An Interchangeable Electric Automobile Transportation System." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 5 p.
 67. DOYLE, G. N. and T. S. WILKINSON. "The Split Compressor Differential Gas Turbine Engine for Vehicle Propulsion." American Society of Mechanical Engineers, Paper No. 66-GT-82, Gas Turbine Conference and Products Show, Zurich, Switzerland, March 13-17, 1966. 11 p.
 68. EDELSON, EDWARD and FRED WARSHOFKY. "Poisons in the Air; a Special Report on Air Pollution." New York: Pocket Books, Inc. 1966. 160 p.
 69. EISENBERG, M. "New Electrochemical Power Sources for Electric Vehicles." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 19 p.
 70. ELDIR, I. ANDREW, (ed). "Technical and Social Problems of Air Pollution." Symposium Sponsored by the Metropolitan Engineers Council on Air Resources and Engineering Foundation, February 24, 1966. New York; 1966. 93 p.
 71. "ELECTRIC CARS INTRIGUE. SEE Utility Executives." *Electrical World*, 153:60-61, March 28, 1960.
 72. "ELECTRIC FORDS IN 1977." *Machine Design*, pp. 12-14, October 27, 1966.
 73. ELECTROCHIMICA CORPORATION. Research and Development Laboratory, Menlo Park, California. "Research on a High Energy Non-Aqueous Battery System." Third Quarterly Progress Report (1 June—31 August 1966) September 15, 1966. 47 p. (AD 802 208)
 74. ERICKSON, CLAUD R. "Design and Operation of Electric Vehicles." Washington; American Public Power Association, 1966. 308 p. Unpublished manuscript.
 75. ERICKSON, CLAUD R. "Electric Vehicle History." *Public Power*, pp. 29-33, Sept. 1966.
 76. ESSO RESEARCH AND ENGINEERING COMPANY. "Automotive Emissions Technology." Presented to the Panel on Electrically Powered Vehicles, Feb. 18, 1967.
 77. ETHYL CORPORATION. "Brief Passenger Car Data—1967." New York; 1967. 42 p.
 78. ETHYL CORPORATION. "The Engine Emission and Medical Aspects of TEL in Motor Gasoline" 1967. Unpublished.
 79. FAUX, GEOFFREY. "Demands and Trends in Prices for Transit." *Monthly Labor Review*, March 1964.
 80. FEDERAL POWER COMMISSION, Bureau of Power. "Development of Electrically Powered Vehicles," February 1967. 50 p.
 81. FEMLING, DON. "A Solid State Electric Motor Control Design." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 7 p.
 82. FINKELSTEIN, T. "Air Engines." *The Engineer*, March 27, 1959, pp. 492-97; Apr. 3, 1959, pp. 522-27; Apr. 10, 1959, pp. 568-71; May 8, 1959, pp. 720-23.
 83. FLYNN, G.; W. H. PERCIVAL, and F. E. HEFFNER. "GMR Stirling Thermal Engine." Meeting of the Society of Automotive Engineers, January 11, 1960.
 84. FLYNN, G., JR.; W. H. PERCIVAL, M. TSOU. "Power from Thermal Energy Storage Systems." Society of Automotive Engineers Paper No. 608B, Combined National Fuels and Lubricants, Power and Transportation Meeting, Philadelphia, Pa., Oct. 29, 1962.
 85. FORD MOTOR COMPANY. "The Control of Automobile Emissions." Revised Edition. Detroit, Mich., December 1966. 8 p.
 86. FRANCIS, HOWARD T. "Space Batteries." Technology Utilization Division, National Aeronautics and Space Administration, NASA SP-5004, Technology Handbook, Washington; U.S. Govt. Print. Off., 1964.
 87. FRANK, FRITZ R. and HERBERT F. HUNGER. "Fourth Status Report on Fuel Cells." U.S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey, July 1963. 70 p. (AD 417 392)
 88. FRYSSINGER, GALEN R. "Electrochemical Energy Storage Systems for Vehicle Propulsion." Fort Belvoir, Va.; U.S. Army Engineer Research and Development Laboratories, November 15, 1965. Unpublished. 51 p.

89. FRYSLINGER, GALEN R. "Fuel Cell—Energy Storage Hybrid Systems for Vehicles." Fort Monmouth, N. J., U.S. Army Electronics Commands, Electronic Components Laboratory, 1966. 25 p. Unpublished.
90. FRYSLINGER, GALEN R. "Low Cost Fuel Cell Electrodes." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966. pp. 14-17.
91. "Fuel Cells—A Survey of Their Prospects of Employment in Electric Vehicles." *Automobile Engineer*, 56:54-58, Feb. 1966.
92. GADDOY, L. D. JR. "Application of Fuel Cell Power Plants for Electrical Drive Systems." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966. pp. 52-56.
93. GAGLIARDI, J. C. "The Effect of Fuel Anti-Knock Compounds and Deposits on Exhaust Emissions." Society of Automotive Engineers, Paper No. 670-128. Automotive Engineering Congress, Detroit, Mich., January 9-13, 1967. 25 p.
94. GENERAL ELECTRIC CO., DIRECT ENERGY CONVERSION OPERATION, Lynn, Massachusetts. "Hydrocarbon-Air Fuel Cells." Semi-Annual Technical Summary Report No. 9 (1 January-30 June, 1966) 1966. 234 p. (AD 640 521).
95. GENERAL MOTORS CORPORATION, Allison Division, Indianapolis, Indiana. "Thermal Battery." — First Quarterly Technical Progress Report (1 July-30 September, 1966) by Bernard Agruss, et al. October 1966. 58 p. (AS 800 246).
96. GENERAL MOTORS CORPORATION, Allison Division, Indianapolis, Indiana. "Thermal Battery." — Second Quarterly Technical Progress Report (1 October-31 December 1966) By Earl H. Hietbrink, et al. January 1967. 49 p. (AS 805 047).
97. "GENERAL MOTORS LOOKS TO THE FUTURE." *Engineering*, 202:927-929, November 25, 1966.
98. GENERAL SERVICES ADMINISTRATION. "Annual Motor Vehicle Report." February 1967.
99. GIACOLETTO, L. J. "Energy Storage and Conversion." *IEEE Spectrum*, 2(2):95-102, Feb. 1965.
100. GILLIS, EDWARD A. "Hydrazine-Air Fuel Cell Power Sources." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966. pp. 41-45.
101. "GM SAYS ELECTRIC CAR IS 10 YEARS AWAY." *Machine Design*, 38:12-15, Dec. 8, 1966.
102. GOLDMAN, MARSHALL I. (ed.) "Controlling Pollution; the Economics of a Cleaner America." Englewood Cliffs, N. J.; Prentice-Hall, Inc., 1967. 175 p.
103. GOLDSMITH, JOHN R. "Carbon Monoxide." A Review of the Carbon Monoxide Conference, Riverside, California, April 11, 1967. *Science*, 157:842-844, August 18, 1967.
104. GOUSE, S. WILLIAM, JR. "High Speed Ground Transport Propulsion." Society of Automotive Engineers, Paper No. 660025, Automotive Engineering Congress, Detroit, Mich., January 10-14, 1966. 8 p.
105. GREEN, LEON, JR. "Energy Needs Versus Environmental Pollution: A Reconciliation." *Science*, 156: 1448-1450, June 1967.
106. HAAGEN-SMIT, A. J. "Chemistry and Physiology of Los Angeles Smog." *Industrial Engineering Chemistry*, 44:1342-1346, 1952.
107. HAASE, R. H. and W. H. T. HUIDEN. "Performance of Land Transportation Vehicles." Report No. RM-3966 RC. Santa Monica, Calif.; Rand Corporation, Jan. 1964.
108. HAINSZEL, W., D. B. LOVELAND, and M. G. FIRKEN. "Lung Cancer Mortality as Related to Resistance and Smoking History: Part 1—White Males." *Journal of National Cancer Institute*, 28: 947, 1962.
109. HALLY, THOMAS J. "Chronic Lead Intoxication from Environmental Contamination: Myth or Fact?" *Archives of Environmental Health*, 12:781-785, June 1966.
110. HARVEY, R. J. and T. C. ROBINSON. "Steam Engine Power Supplies." Society of Automotive Engineers, Inc. Paper No. 883B, Jan. 8, 1964.
111. HASS, ROBERT H. "Exhaust Treatment Apparatus and Method." U.S. Patent No. 3,257,798. June 28, 1966.
112. HAYNES, W. P. and H. B. NELSON. "Evaluation of a Battery-Powered Truck." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 20 p.
113. HEAD, ROY. "Technological Change as it Relates to Air Pollution." In: National Commission on Technology, Automation, and Economic Progress. "Technology and the American Economy." Volume V: Applying Technology to Unmet Needs. Appendix, pp. V-135-V-145, Washington: U.S. Govt. Print. Off., February 1966.
114. "HEALTH HAZARDS OF COMMUNITY AIR POLLUTION." In Air pollution—1966; hearings before Subcommittee on Air and Water Pollution of the Committee on Public Works, U.S. Senate, 89th Congress, 2nd session, Washington, U.S. Gov't. Print. Off., 1966. pp. 22-53.
115. HEATH, CARL E., et al. "Hydrocarbon-Air Fuel Cell." Fifth Semiannual Report. ESSO Research and Engineering Company. Government Research Laboratory, Linden, New Jersey. (1 January 1966-31 July 1966) October 1966. 111 p. (AD 802 671).
116. HELFNER, F. E. "Highlights From 6500 Hours of Stirling Engine Operation." Society of Automotive Engineers, Paper No. 949D, Jan. 11, 1965.
117. HELLY, W. "Impact of Electric Power Systems on Urban Traffic Flow, Control, and Facilities." Symposium on Power Systems for Electric Vehicles, Columbia University, New York, New York, April 6-8, 1967.
118. HELTEMIS, C. J., JR. and C. A. VANSANT. "Power Sources for Vehicles — 1966 Status Report." Inter-society Energy Conversion Engineering Conference. Sept. 1966. Proceedings.
119. HENDLER, B. S. "Battery Electric Road Vehicles." Second International Conference on Lead. Arnhem, The Netherlands, October 4-7, 1965, 5 p.
120. HENDER, B. S. "Recent Developments in Battery Electric Vehicles." Institute of Electrical Engineers. Proceedings, 112(12):2297-2308, Dec. 1965.
121. HENDERSON, R. E. "Design Applications of Direct Energy Converters." American Society of Mechanical Engineers, Paper No. 65-MD 50, Design Engineering Conference and Show, New York, New York, May 17-20, 1965. 7 p.
122. HERBERT, W. S. "Battery Research and Fuel Cells." Society of Automotive Engineers, Inc., Paper No. S347, South Bend Section Meeting, Mar. 19, 1962. 9 p.
123. HEREDY, L. A., et al. "The Atomic International Sodium-Air Cell." Symposium on Power Systems for Electric Vehicles, Columbia University, New York, April 6-8, 1967.

124. HEYMANN, H. JR. "Transportation Technology and the Real World." The RAND Corporation, P-2735, June 1963.
125. HIBBEN, RODERICK D. "Allis-Chalmers Pushes Fuel Cell Efforts." *Aviation Week and Space Technology*, (86) 65,67,69,71, January 23, 1967.
126. HINIS, EDWARD. "The Utilities' View of Electric Automobiles." Third Annual Meeting of the American Institute of Aeronautics and Astronautics. Paper No. 66-981, Boston, Mass., November 29-December 2, 1966, 3 p.
127. HOCHGELANG, C. F. "1960 Shapes Up As Key Year For Renaissance of the Electric Vehicle." *Electrical World*, (153) 44-45, January 10, 1960.
128. HOFFMAN, GEORGE A. "Automobiles—Today and Tomorrow." The RAND Corporation, Santa Monica, Calif. November 1962, 184p. (AD 609 737).
129. HOFFMAN, GEORGE A. "Battery Operated Electric Automobiles." The RAND Corporation, Santa Monica, Calif. March 1963, 31 p. (AD 298 282).
130. HOFFMAN, GEORGE A. "Systems Design of Electric Automobiles." Los Angeles, Calif.: University of California, 1967, 41 p. Unpublished.
131. HOFFMAN, GEORGE A. "The Electric Automobile." *Scientific American*, (215) 34-40, Oct. 1966.
132. HOPKINS, R. E. "AC Electric Drive for Off Highway Electric Vehicles." Society of Automotive Engineers, Inc., Paper No. S431, Earthmoving Industry Conference, Central Illinois Section, Peoria, Ill., Apr. 6-7, 1965, 39 p.
133. HOSICK, T. A. "Elliptocline Progress." *The Steam Automobile*, #4, 1966.
134. HOUSING AND HOME FINANCE AGENCY. "Housing Statistics, Annual Data." Washington, D. C., March 1960.
135. HOWARD, PAUL L. "Wet Cell Batteries for Power." *Product Engineering*, (31) 75-82, Feb. 15, 1960.
136. HUGLE, WILLIAM B. "Microcircuits, Semiconductors, and Controls for the Electronic Car." National Electric Automobile Symposium, San Jose, California, Feb. 24-25, 1967, 7 p.
137. HULSTRAND, K. A. "Static Adjustable Frequency Drives." *Control Engineering*, (11) 57-63, April 1964.
138. HUNGER, HERBERT H., et al. "Third Status Report on Fuel Cells." U.S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, June 1, 1962, 129 p. (AD 286 686).
139. HUNGER, HERBERT F. "Low Power Ground Applications." 17th Annual Power Sources Conference, May 21-23, 1963, pp. 80-82.
140. INSTITUTE FOR DEFENSE ANALYSES. Research and Engineering Support Division, Arlington, Va. "A DOD Research Program for Electrochemical Science with Applications to Energy Storage and Conversion." IDA Electrochemical Research Panel, G. C. Szego, Chairman. Dec. 1965, 130 p. (AD 482 433).
141. JENKINS, JONATHAN and RUSSEL E. WINN. "How Near Are Fuel-Cell Motor Cars?" *New Scientist*, No. 414, pp. 222-225, Oct. 22, 1964.
142. JOHNSON, A. O. "Fuel Economizer and Exhaust Gas Purifier for Internal Combustion Engines." U.S. Patent No. 3,236,214. Feb. 22, 1966.
143. KAIN, J. F. "A Re appraisal of Metropolitan Transport Planning." Commonwealth Bureau of Roads Symposium on the Economics of Roads and Road Transport, Melbourne, Australia, July 17, 1967.
144. KEMP, L. C., JR. "A Look at the Economics of Manufacturing Unleaded Gasoline." American Petroleum Institute, Division of Refining, 32nd Midyear Meeting, Los Angeles, Calif., May 16, 1967, 2 p.
145. KENT, C. E., and W. N. CARSON, JR. "Magnesium-Air Cells." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966.
146. KINOSIAN, JOHN R., JOHN R. MAGA, and JOHN R. GOLDSMITH. "The Diesel Vehicle and Its Role in Air Pollution." A report to the California Legislature, Berkeley, California: Department of Public Health, Bureau of Air Sanitation, Dec. 1962, 96 p.
147. KIRKLAND, T. G. "5 KW Hydrocarbon-Air Fuel Cell Power Plant." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966, pp. 35-39.
148. KIRKLAND, T. G. and D. J. LOOFT. "Fuel Cells—Present Status and Development Problems." Society of Automotive Engineers. Paper No. 660230, Earthmoving Industry Conference, Central Illinois Section, Peoria, Ill., Apr. 5-6, 1966, 14 p.
149. KIRTLAND, JOHN A. "Vehicle Electric Drive Development in the Military." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. Proceedings, 19 p.
150. KLEIN, B. H., W. H. MECKLING, and E. G. MESTHENE. "Military Research and Development Policies." December 1958, (AD 226128, also available as The RAND Corporation Publication No. R-333).
151. KRISS, RALPH H. "The Caterpillar 100 Ton Electric Drive Truck." Society of Automotive Engineers. Paper No. 660228, Earthmoving Industry Conference, Central Illinois Section, Peoria, Ill., Apr. 5-6, 1966, 3 p.
152. KUMMER, JOSEPH T. and NEILL WEBER. "A Sodium-Sulfur Secondary Battery." Society of Automotive Engineers, Inc. Paper No. 670179, Automotive Engineering Congress, Detroit, Michigan, Jan. 9-13, 1967, 7 p.
153. KUSKO, ALEXANDER and LEE T. MAGNUSON. "Vehicle Electric Drive Systems." Society of Automotive Engineers, Inc. Paper No. 660761, Combined Power Plant and Transportation Meeting, Chicago, Ill., Oct. 17-21, 1966, 15 p.
154. LANDSBERG, HANS H., LEONARD L. FISCHMAN, and JOSEPH L. FISHER. "Resources in America's Future." Baltimore, Md., Johns Hopkins Press, 1963, 1017 p.
155. LAUK, FRANCIS, O. A. UYEHARA, and P. S. MYERS. "An Engineering Evaluation of Energy Conversion Devices." Society of Automotive Engineers, Inc. Paper No. 463A, presented at meeting, Jan. 8-12, 1962, 12 p.
156. LAUCK, FRANCIS, O. A. UYEHARA and P. S. MYERS. "New Power Sources Aren't Apt to Put Old Standbys on Shelf." *SAE Journal*, (70) 27-33, Apr. 1962.
157. LAWSON, L. J., ROBERT P. BORLAND, and CLARENCE G. PUCHY. "Optimal Control System Performance for an A-C Electric Vehicular Drive." Society of Automotive Engineers. Paper No. 660135, Automotive Engineering Congress, Detroit, Michigan, Jan. 10-14, 1966, 9 p.
158. LAWSON, S. D., J. F. MOORE, and J. B. RATHER, JR. "A Look at Lead Economics in Motor Gasoline." American Petroleum Institute, Division of Refining. Preprint No. 36 67, 32nd Midyear Meeting, Los Angeles, Calif., May 16, 1967, 36 p.

159. LAZARIDIS, L. J. and P. G. PANTAZELIS. "Design of a 5-Kilowatt Flame Heated Thermionic Power Supply." 1966 Thermionic Conversion Specialist Conference, Houston, Texas, Nov. 2-4, 1966. 6 p.
160. LeCLAIR, T. G. and D. V. RAGONE. "Zinc-Air Battery for Motive Power." Institute of Electrical and Electronics Engineers. Paper No. 31 PP 67-134, I.E.E.E. Winter Power Meeting, New York, N.Y., Jan. 29-Feb. 3, 1967.
161. LEE, Y. C. "Fuel Cells as Power Sources." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 15 p.
162. LENTZ, E. C. "Muffler." U.S. Patent No. 3,201,207. Aug. 17, 1965.
163. LESSING, LAWRENCE. "Assault on the Internal-Combustion Engine." *Fortune*, pp. 79-83, 180-184, July 1967.
164. LESSING, LAWRENCE. "Bringing the Fuel Cell Down to Earth." *Fortune*, pp. 128-131, Sept. 1966.
165. LEVY, ALEXANDER. "Ammonia Air Fuel Cell System for Vehicles Propulsion." Final Technical Report (27 July 1964-27 July 1965). Pratt & Whitney Aircraft, Division of United Aircraft Corporation, East Hartford, Conn., July 1965. (AD 273 143).
166. LEWIS, RUSSELL M. "A Forward Look at Tube Transportation." Society of Automotive Engineers. Paper No. 660023, Automotive Engineering Congress, Detroit, Mich., Jan. 10-14, 1966. 8 p.
167. LIEBHAFSKY, H. A. "Fuel Cells and Fuel Batteries—an Engineering View." *IEEE Spectrum*, 3:48-56, Dec. 1966.
168. LINDEN, DAVID, et. al. "The Future of Fuel Cells." Panel discussion, Proceedings of the 17th Annual Power Sources Conference, May 21-23, 1963. pp. 80-84.
169. LINDGREN, NILS. "Electric Cars — Hope Springs Eternal." *IEEE Spectrum*, 4(4):48-60, Apr. 1967.
170. LOWMY, WILEAN P. "The Climate of Cities." *Scientific American*, Vol. 217, No. 2, pp. 15-23, August 1967.
171. "LUCAS BACKS THE ZINC-AIR BATTERY." *Engineering*, (203)204-205, Feb. 10, 1967.
172. LUCKING, WALTER T. "Energy: Evolution — Revolution." *Edison Electric Institute Bulletin*, pp. 282-287, September 1965.
173. LYNN, D. A.; W. R. OTT; E. C. TAROR, and R. SMITH. "Present and Future Commuter Exposures to Carbon Monoxide." Air Pollution Control Association Annual Meeting. Paper No. 67-5, Cleveland, Ohio, June 12-16, 1967.
174. MAASS, A. "Design of Water-Resource Systems." Harvard University Press, 1962.
175. MAGA, JOHN A. and GERHARDT C. HAAS. "The Development of Motor Vehicle Exhaust Emission Standards in California." Air Pollution Control Association. 53rd Annual Meeting, Cincinnati Ohio, May 25, 1960. 12 p.
176. MAGNUS, AGATHA C. "Treatment of Substances with Ultrasonic Vibrations and Electro-Magnetic Radiations." U.S. Patent No. 3,306,835, Feb. 28, 1967.
177. "MAN VS. AUTO—TOM SWIFT TO THE RESCUE." *Newsweek*, 69: 46-47, Jan. 9, 1967.
178. MANOS, N. "Comparative Mortality Among Metropolitan Areas of the U.S. — 102 Causes of Death." Public Health Service Publication No. 562, 1957. 143 p.
179. MAPHAM, NIVILLE and JOHN MUNGENAST. "Semiconductor Power Controls for Electric Vehicles." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 11 p.
180. MARKS, CRAIG. "The General Motors Battery-Electric and Fuel Cell Powered Vehicles." A Briefing for the Panel on Electrically Powered Vehicles, Washington, February 18, 1967. General Motors Corporation 30 p. Unpublished.
181. MARKS, CRAIG, EDWARD A. RISHAVY, and FLOYD A. WYCZALEK. "Electrovan — a Fuel Cell Powered Vehicle." Society of Automotive Engineers. Paper No. 670176, Automotive Engineering Congress and Exposition, Detroit, Mich., Jan. 9-13, 1967. 14 p.
182. MARWOOD, R. M. and W. H. PRUESSER. "Potential Performance of Gas Turbine Powerplants." Society of Automotive Engineers. Paper No. 650715, Combined Powerplant and Transportation Meeting, Cleveland, Ohio, Oct. 18-21, 1965. 9 p.
183. MATTOON, D. R. "Ceramic Muffler with Resilient Sealing Gaskets." U.S. Patent No. 3,227,242. Jan. 4, 1966.
184. MAY, et. al. "Combustion System for Internal Combustion Engines." U.S. Patent No. 3,124,113. Mar. 10, 1964.
185. MAYER, M. "A Compilation of Air Pollution Emission Factors for Combustion Processes, Gasoline Evaporation, and Selected Industrial Processes." U.S. Department of Health, Education and Welfare, Public Health Service, 1965.
186. MEANS, T. T. "Locomotive Type Electric Drive for Off Highway Vehicles." Society of Automotive Engineers, Inc. Paper No. 896A, National Farm, Construction and Industrial Machinery Meeting, Milwaukee, Wis., Sept. 14-17, 1964. 11 p.
187. MEIJER, R. J. "Philips Stirling Engine Activities." Society of Automotive Engineers, Inc. Paper No. 946E, Jan. 11, 1965.
188. MENNICKEN, J., et. al. "Supplement Air Supply Devices." U.S. Patent No. 3,294,074. Dec. 27, 1966.
189. MEURER, S. "Ignition Device." U.S. Patent No. 3,107,658, Oct. 22, 1963.
190. MEYER, J., J. F. KAIN, and M. WOHL. "The Urban Transportation Problem." Harvard University Press, Cambridge, Mass., 1965.
191. MIDDLETON, JOHN T. "A Fresh Opportunity for Industry." *Environmental Science and Technology*, March 1967.
192. MIDDLETON, JOHN T. "Air Pollution Control — Preventive Medicine." American Medical Association, Section on Preventive Medicine, 116th Annual Convention, Atlantic City, New Jersey, June 19, 1967. 13 p.
193. MIDDLETON, JOHN T. "Future Air Quality Standards and Motor Vehicle Emission Restrictions." Paper No. A-2, National Conference on Air Pollution, Washington, D. C. December 12-14, 1966.
194. MILLMAN, V. "Advanced Technology Applied to the Steam Powered Vehicle." Society of Automotive Engineers. Paper No. 931A, Oct. 19, 1964.
195. MINER, S. S. "New Revolver-Like Steam Engine." *Popular Science*, February 1966.
196. MITTELSTAEDT, G. S. "Ozonizing Means in Combustion Engines." U.S. Patent No. 3,157,172. Nov. 17, 1964.
197. MOBIL OIL CO. "Results of Exhaust Gas Analysis of Williams Engine by Mobil Oil Co." Chicago, Ill.; Steam Automobile Club of America, Inc., 1967.
198. MONTGOMERY, JAMES E., HELMUT R. SCHELP, and DONALD G. FURST. "200-300 HP Gas Turbine Engine Family for the U.S. Army." Society of

- Automotive Engineers. Paper No. 795A, Automotive Engineering Congress, Detroit, Mich., Jan. 13-17, 1964. 19 p.
199. MORGAN, G. B. and R. HOMAN. "Determination of Atmospheric Metals by Atomic Absorption Spectrometry." Conference on Analytical Chemistry and Spectroscopy, March 1967.
 200. MORRELL, JACQUE C. "Apparatus and Process for Treatment of Exhaust Gases From Internal Combustion Engines. U.S. Patent No. 3,248,872. May 3, 1966.
 201. NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL. Committee on Pollution. "Waste Management and Control." Report to the Federal Council for Science and Technology. Washington: NAS-NRC. Publication No. 1400, 1966. 257 p.
 202. NATIONAL ACADEMY OF SCIENCES NATIONAL RESEARCH COUNCIL. Highway Research Board. "Vehicle Characteristics" 41st Annual Meeting, Jan. 8-12, 1962. Washington: NAS-NRC, 1962. Bulletin No. 334. 53 p.
 203. NATIONAL ELECTRIC AUTOMOBILE SYMPOSIUM, San Jose, California, Feb. 24-25, 1967. Abstracts. 15 p.
 204. NEIR, T. E. "Engine." U.S. Patent No. 3,180,327. Apr. 27, 1965.
 205. NILDERCORN, JOHN H. and EDWARD F. R. HEARLE. "Recent Land Use Trends in Forty-Eight American Cities." The RAND Corporation, RM-36641-FF.
 206. NORTH AMERICAN AVIATION, INC. Space and Information Systems Division, El Segundo, Calif. "Auxiliary Power Sources in Space." Technical Documentation: Volume I of III (fuel cells) 156 p. July 12, 1962. (AD 282 474).
 207. O'DONNELL, LAURENCE G. "Shape of the Future: Concern Over Pollution of Air and Safety Will Force Major Changes in Automobiles." *The Wall Street Journal*, 169 (15): 1,10 January 23, 1967.
 208. ONJANOW, N. "A-C Drive Offers System Design Flexibility." *Electro-Technology*, 66 (6):131-137, Dec. 1960.
 209. OSBORNE, DANIEL and ZACH STEWART. "Human Factors in Electric Automobiles." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967.
 210. OSBORNE, P. S. "Preinduction Means and Method for Treating a Fuel Air Mixture." U.S. Patent No. 3,057,335, Oct. 9, 1962.
 211. OSBORNE, P. S. "Preinduction Means and Method for Treating a Fuel Air Mixture for Reduction of Nitrous Oxides." U.S. Patent No. 3,146,768. Sept. 1, 1964.
 212. OSTHOFF, R. C. "Potential Battery Systems in Vehicle Propulsion." Symposium on Power Systems for Electric Vehicles, Columbia University, New York, April 6-8, 1967.
 213. OTT, WAYNE, JOHN F. CLARKE, and GUNTIS OZOLINS. "Calculating Future Carbon Monoxide Emissions and Concentrations from Urban Traffic Data." Public Health Service, Bureau of Disease Prevention and Environmental Control, National Center for Air Pollution Control, Cincinnati, Ohio. June 1967. 40 p. (Public Health Service Publication No. 99-AP-41.)
 214. PAHNKE, A. J. and E. C. SQUIRE. "No Effect on Exhaust Emission Found in 18 Months Consumer-Car Test." *Oil and Gas Journal*, December 12, 1966.
 215. PAHNKE, A. J., et al. "Exhaust Manifold Reactor." U.S. Patent No. 3,302,394. Feb. 7, 1964.
 216. PALMER, N. U. "Zinc-Air Batteries for the Electric Vehicle." Symposium on Power Systems for Electric Vehicles, Columbia University, New York, N. Y. April 6-8, 1967.
 217. PILTSCH, GERHARD and IVAN M. SWATMAN. "A Gas Turbine Super Transport Truck Power Package." Society of Automotive Engineers, Paper No. 991B, Automotive Engineering Congress, Detroit, Mich., Jan. 11-15, 1965. 30 p.
 218. PERCIVAL, W. H. "Fluorochemical Vapor Engine." Society of Automotive Engineers. Paper No. 931B., Oct., 1964.
 219. PLUST, HEINZ G. "Fuel Cells: Principle of Operation, Design and Present State of the Art in Fuel Cell Development." (Translated from *Neue Zürcher Zeitung*, Technology Supplement, No. 133(3) Jan. 12, 1966) AD 805 336, 33 p.
 220. "POLLUTION BY EXHAUSTS U.S. LAW AND A U. K. SYSTEM." *Engineering*, 203:213 216, Feb. 10, 1967.
 221. PORTER, K. W. and L. H. WILLIAMS. "Gas Turbines for Emergency Vehicles." Society of Automotive Engineers. Paper No. 650460, Mid-year Meeting, Chicago, Ill., May 17-21, 1965. 13 p.
 222. POTTER, B. V. "Method of Cleaning Engine Exhaust Gases." U.S. Patent No. 3,100,376. Aug. 13, 1963.
 223. POWER INFORMATION CENTER, INSTITUTE FOR COOPERATIVE RESEARCH, UNIVERSITY OF PENNSYLVANIA. "Background Material for the Study of the National Space Power Program." 6 Volumes. Philadelphia, Penna., October 1964.
 224. "POWER TRANSMISSION SYSTEM OF THE BERLIET TX 40 DIESEL-ELECTRIC EARTH-MOVING VEHICLE." *Brown Boveri Review*, 52(9/10):761-770, Sept./Oct., 1965.
 225. QUADE, E. S. (ed). "Analysis for Military Decisions." Rand McNally & Co., Chicago, 1964.
 226. QUADE, E. S. and W. I. BOUCHER, (eds). "Systems Analysis and Policy Planning: Applications in Defense." A RAND Corporation Study. (Unpublished).
 227. QUAN, D. "The Design and Development of the Orenda OT-4 Gas Turbine." American Society of Mechanical Engineers. Paper No. 66-GT/M-23, Gas Turbine Conference and Products Show, Zurich, Switzerland, March 13-17, 1966. 10 p.
 228. QVALE, E. B. "An Investigation of Stirling Type Engines." Sc. D. Thesis, Mechanical Engineering Dept., Mass. Inst. of Tech., Fall 1966.
 229. RAGONE, DAVID. "Review of Industry Battery R&D." A Briefing for the Panel on Electrically Powered Vehicles, Washington, February 18, 1967. General Motors Corporation 30 p. Unpub.
 230. REID, WILLIAM T. "Energy Sources for Electrically Powered Vehicles." *Battelle Technical Review* pp. 9-15, April 1965.
 231. REID, WILLIAM T. "Kilowatts for Cars — a Comparison of Energy Costs for Electric Automobiles." American Institute of Aeronautics and Astronautics. Paper No. 66-978, Third Annual Meeting, Boston, Mass., Nov. 29-Dec. 2, 1966. 7 p.
 232. REUTER, ROBERT M. and GEORGE W. ECKERT. "Method of Operating an Internal Combustion Engine and Motor Fuel Therefor." U.S. Patent No. 3,164,138 January 5, 1965.
 233. RHODES, K. H. "Throttle Closed Position Limiter." U.S. Patent No. 3,266,473, Aug. 16, 1966.
 234. RIDKIR, R. G. and J. A. HENNING. "The Determinants of Residential Property Values with Special Refer-

- ence to Air Pollution." *Review of Economics and Statistics*, 49:246-257, 1967.
235. RIDKER, RONALD G. "Economic Costs of Air Pollution: Studies in Measurement." New York: Frederick A. Praeger, 1967. 214 p.
 236. RISHAVY, E. A., W. D. BOND, and T. A. ZECHIN. "Electrovair—a Battery Electric Car." Society of Automotive Engineers. Paper No. 670175, Automotive Engineering Congress and Exposition, Detroit, Mich., Jan. 9-13, 1967. 12 p.
 237. SCHAEFER, VINCENT J. "Ice Nuclei from Automobile Exhaust and Iodine Vapor." *Science*, 154:1555-1557, December 23, 1966.
 238. SCHAEFER, MAURICE J. "An Evaluation of Fuel Cell Systems for Military Vehicle Propulsion and Portable Electric Power Generation." California Research Corporation, Special Report No. 2, Richmond, California, Feb. 1, 1965. (AD 456 740).
 239. SCHULTE, JOHN H. "Effects of Mild Carbon Monoxide Intoxication." *Archives of Environmental Health*, Vol. 7, Nov. 1963, pp. 30-36.
 240. SEARUYS, M. Y. A. M. "Explosion Engines." U.S. Patent No. 3,190,275, June 22, 1965.
 241. SHAIR, R. C., H. N. SEIGER, and A. E. LYALL. "Progress on Lithium Batteries." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 12 p.
 242. SHIMOTAKE, H. and E. J. CAIRNS. "Performance Characteristics of a Sodium-Bismuth Cell." Electrochemical Society, Spring Meeting, Dallas, Texas, 1967. 4 p.
 243. SHIPPS, P. R. "A Zinc-Air Secondary Battery System for Vehicle Propulsion." Paper No. GA-7085. Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966.
 244. SHIPPS, P. R. "Metal-Air Systems: Secondary Metal Air System." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966, pp. 86-88.
 245. SIARIK, WALTER. "An A-C Individual Wheel Drive System for Land Vehicles." Society of Automotive Engineers. Paper No. 660134, Automotive Engineering Congress, Detroit, Michigan, January 10-14, 1966. 8 p.
 246. SLAYTER, GAMES, *et al.* "Catalytic Muffing System for Reducing Contaminants in Exhaust Gases." U.S. Patent No. 3,166,895, January 26, 1965.
 247. SLAYTER, GAMES, *et al.* "Muffler Internally Coated with Highly Refractory Fibers." U.S. Patent No. 3,233,697, February 8, 1966.
 248. SOLTAN, J. P. "Combustion Apparatus." U.S. Patent No. 3,210,161, October 5, 1965.
 249. SPIAK, PETER and NOEL PINNY. "The Classification of Gas Turbine and Piston Engines for Competition Purposes." Society of Automotive Engineers. Paper No. 996B, International Automotive Engineering Congress, Detroit, Mich., Jan. 11-15, 1965. 16 p.
 250. SPORN, PHILIP. "Development of National Policies with Respect to Natural Gas, Coal, and Oil, and Nuclear and other New Sources of Power." National Conference on Air Pollution, December 12-14, 1966, Washington, D. C. 6 p.
 251. STANDARD OIL COMPANY (NEW JERSEY). "Automotive Emissions Technology." February 1967. 20 p. Unpublished.
 252. STARKMAN, E. S. "The Prospects for Electric Trucks." 1967 Truck Operations Seminar, Los Angeles, Calif., Apr. 19, 1967. University of California, Berkeley, College of Engineering. 10 p.
 253. STATE UNIVERSITY OF NEW YORK (ALFRED). COLLEGE OF CERAMICS. "Fuel Cell Bibliography." Contract AF 33 (657)-7564 June 15, 1962. 116 p. Mimeographed.
 254. STEAM AUTOMOBILE CLUB OF AMERICA, INC. "Results of Exhaust Gas Analysis by Mobil Oil Company." 1917 East 71st Street, Chicago, Illinois.
 255. STEBAR, R. F. and D. A. BROWNSON. "Factors Influencing the Effectiveness of Air Injection in Reducing Exhaust Emissions." Society of Automotive Engineers. Paper No. 650526, Mid-Year Meeting, Chicago, Ill., May 17-21, 1965. 20 p.
 256. STEIN, B. R. "Status Report on Fuel Cells." U.S. Army. Army Research Office, Washington, D. C. ARO Report No. 1, June 1959. 116 p. (AD 219 389).
 257. STEIN, B. R. "Second Status Report on Fuel Cells." U.S. Army. Army Research Office, Washington, D. C. ARO Report No. 2, December 1960. 76 p. (AD 253 705).
 258. STEINHAGEN, WILLIAM K. "Air Pollution Control Methods for the Gasoline Powered Internal Combustion Engine." A Briefing for the Panel on Electrically Powered Vehicles. Washington; February 18, 1967. General Motors Corporation. 30 p. Unpublished.
 259. STERN, ARTHUR C., (ed.) "Air Pollution." New York: Academic Press, 1962. 2 volumes.
 260. STERN, ARTHUR C. "How the United States Looks at the Auto Exhaust Problem." Air Pollution Congress of the Swedish National Clean Air Council, Stockholm, Sweden, May 5, 1965. Washington; U.S. Public Health Service, 1965. 54 p.
 261. STOPPS, GORDON J., *et al.* "Lead Research: Current Medical Development." Industrial Hygiene Foundation, Pittsburgh, Pennsylvania, 31st Annual Meeting, October 18-19, 1966. 23 p.
 262. STUMPF, FRIEDRICH. "Internal Combustion Engine Construction and Method." U.S. Patent No. 3,192,912, July 6, 1965.
 263. STURM, W. E. "An Allectric Future—Now." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 5 p.
 264. STYLES, H. E., J. VRIES, and J. LAWTHOR. "Public Health Aspects of Air Pollution from Diesel Vehicles." World Health Organization, WHO/AP/67.28, Geneva, Switzerland, 1967.
 265. SWINKLES, D. A. J. "Lithium-Chlorine Battery." *Journal of the Electrochemical Society*, 113(1):6-10, Jan. 1966.
 266. "SYMPOSIUM ON LEAD." *Archives on Environmental Health*, 8:202-354, Feb. 1964.
 267. SYMPOSIUM ON POWER SYSTEMS FOR ELECTRIC VEHICLES, COLUMBIA UNIVERSITY, NEW YORK, N. Y., APR. 6-8, 1967. Extended abstracts. 1967. 207 p.
 268. SZIGO, G. C. "Economic and Logistic Considerations." Proceedings of the 17th Annual Power Sources Conference, May 21-23, 1963, pp. 88-92.
 269. SZIGO, GEORGE C. "Economics, Logistics, and Optimization of Fuel Cells." Institute for Defense Analysis, Research and Engineering Support Division, Arlington, Va. December 1965. 59 p. (AD 477 429).
 270. TENNISWOOD, DAVID M. and HELMUT A. GRALTZEL. "Minimum Road Load for Electric Cars." Society of Automotive Engineers. Paper No. 670177, Automotive Engineering Congress, Detroit, Mich., Jan. 9-13, 1967. 10 p.

271. TENNY, PETER, *et al.* "Portable Hydrazine-Air Fuel Cell Batteries." Proceedings of the 20th Annual Power Sources Conference, Atlantic City, N. J., May 24-26, 1966, pp. 39-41.
272. THE REGIONAL PLAN ASSOCIATION. "Transportation and the Central Manhattan Business District." *Regional Plan News*, No. 82, February 1966.
273. THERMO-ELECTRON ENGINEERING CORPORATION. "Advanced Steam Engine for Automotive Propulsion." Waltham, Mass., February 1967.
274. TERUNEN, W. A. and J. S. COLTMAN. "The General Motors Research GT-309 Gas Turbine Engine." Society of Automotive Engineers. Paper No. 650-714. Combined Powerplant and Transportation Meeting, Cleveland, Ohio, Oct. 18-21, 1965, 17 p.
275. UNDERWOOD, M. ARTHUR. "Les possibilités du moteur Stirling." *Ingenieurs de L'Automobile*, 12(63), October, 1963, pp. 655-664.
276. U.S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES. "Department of Defense Research on Unconventional Vehicular Propulsion." Briefing for the Panel on Electrically Powered Vehicles. Washington, D. C. February 18, 1967, 18 p.
277. U.S. CONGRESS, HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND ASTRONAUTICS, SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT. "Environmental Pollution; A Challenge to Science and Technology." 89th Congress, 2nd session. Washington; U.S. Government Print. Off., 1966.
278. U.S. CONGRESS, HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND ASTRONAUTICS, SUBCOMMITTEE ON SCIENCE, RESEARCH, AND DEVELOPMENT. "The Adequacy of Technology for Pollution Abatement." 89th Congress, 2nd. session. Washington; U.S. Government Print. Off., 1966, 2 volumes.
279. U.S. CONGRESS, SENATE COMMITTEE ON COMMERCE. "Electric Vehicles and Other Alternatives to the Internal Combustion Engine." Joint Hearings before the Committee on Commerce and the Subcommittee on Air and Water Pollution. Committee on Public Works, U.S. Senate, 90th Congress, 1st session, March 14-17, 1967 and April 10, 1967. Washington; U.S. Government Print. Off., 1967.
280. U.S. CONGRESS, SENATE COMMITTEE ON PUBLIC WORKS. "Air Pollution—1966." Hearings before the Subcommittee on Air and Water Pollution, 89th Congress 2nd. session, Washington; U.S. Government Print. Off., 1966, 453 p.
281. U.S. CONGRESS, SENATE COMMITTEE ON PUBLIC WORKS. "Air Pollution—1967 (Air Quality Act)." Hearings before the Subcommittee on Air and Water Pollution, 90th Congress, 1st session, Washington; U.S. Government Print. Off., 1967, 4 volumes.
282. U.S. DEPARTMENT OF COMMERCE. Panel on Invention and Innovation. "Technological Innovation; Its Environment and Management." Washington; U.S. Govt. Print. Off., 1967, 85 p.
283. U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE. "Automotive Air Pollution." A Report to the United States Congress. Washington, U.S. Govt. Print. Off., 1965.
284. U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. "Automotive Air Pollution." A Second Report to the United States Congress. Washington, U.S. Govt. Print. Off., 1965.
285. U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. "Automotive Air Pollution." A Third Report to the United States Congress. Washington, U.S. Govt. Print. Off., 1966.
286. U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. "Automotive Air Pollution." A Fourth Report to the United States Congress. Washington, U.S. Govt. Print. Off., 1966.
287. U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. "Automotive Air Pollution." A Fifth Report to the United States Congress. Washington, U.S. Govt. Print. Off., 1967.
288. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, OFFICE OF THE ASSISTANT SECRETARY FOR PROGRAM COORDINATION. "Application of Benefit-Cost Analysis to Motor Vehicle Accidents." August 1966.
289. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE. "Survey of Lead in the Atmosphere of Three Urban Communities." January 1965. (Publication No. 999 AP 12).
290. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "A Digest of State Air Pollution Laws." Washington, U.S. Govt. Print. Off., 1966. (PHS Publication No. 711), 292 p.
291. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Air Pollution—A National Sample." Washington, D.C., U.S. Govt. Print. Off., 1966 (PHS Publication No. 1562) 27 p.
292. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Air Pollution Publications; A Selected Bibliography, 1963-1966." Washington, U.S. Govt. Print. Off. (PHS Publication No. 978) 1966, 144 p.
293. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Carbon Monoxide; A Bibliography with Abstracts." Compiled by Anna Grossman Cooper. Washington, U.S. Govt. Print. Off., 1966. (PHS Publication No. 1503) 440 p.
294. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Effects of the Ratio of Hydrocarbon to Oxides of Nitrogen in Irradiated Auto Exhaust." Washington, Oct. 1966.
295. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Guide to Research in Air Pollution; Projects Active in Calendar Year 1966." (PHS Publication No. 981) 82 p.
296. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Motor Vehicles, Air Pollution, and Health." A Report of the Surgeon General to the U.S. Congress." Washington, U.S. Govt. Print. Off., 1962. (87th Cong., 2d. sess., House Document No. 489) 510 p.
297. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "State and Local Programs in Air Pollution Control." Washington, U.S. Govt. Print. Off., 1966 (PHS Publication No. 1549) 16 p.
298. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "The Federal Air Pollution Program." Washington, U.S. Govt. Print. Off., 1966. (PHS Publication No. 1560) 52 p.

299. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "The Sources of Air Pollution and Their Control." Washington, U.S. Govt. Print. Off., 1966 (PHS Publication No. 1548) 15 p.
300. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. PUBLIC HEALTH SERVICE, DIVISION OF AIR POLLUTION. "Today and Tomorrow in Air Pollution." Washington, U.S. Govt. Print. Off. (PHS Publication No. 1555) 1966. 28 p.
301. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE. Task Force on Environmental Health and Related Problems. "A Strategy for a Livable Environment." A Report to the Secretary of Health, Education, and Welfare. Washington; June 1967.
302. U. S. DEPARTMENT OF THE INTERIOR. Bureau of Mines. Petroleum Res. Center, Bartlesville, Okla. "Motor Gasolines, Winter 1966-67." Prepared by O. C. Blade. (Mineral Industry Surveys, Petroleum Products Survey No. 50). Washington; 1967. 38 p.
303. U. S. FEDERAL AVIATION AGENCY, AERONAUTICAL CENTER, OKLAHOMA CITY, OKLA. "Fuel Cells; Selected References." Bibliographic List No. 2, November 1964, 103 p. (AD 608 880).
304. U. S. NATIONAL COMMISSION ON TECHNOLOGY, AUTOMATION, AND ECONOMIC PROGRESS. "Technology and the American Economy: A Report." Vol. 1, February 1966. Washington, U.S. Govt. Print. Off., 1966. 115 p.
305. U. S. NAVAL RESEARCH LABORATORY, TECHNICAL INFORMATION DIVISION, WASHINGTON, D. C. "Direct Energy Conversion Literature Abstracts." June 1966. 116 p. (AD 635 584).
306. U. S. PRESIDENT'S SCIENCE ADVISORY COMMITTEE. Environmental Pollution Panel. "Restoring the Quality of Our Environment." Washington, U.S. Govt. Print. Off., 1965. 317 p.
307. VAN WITTEVLEN, R. A. J. O. "The Philips Stirling Engine: Present and Future." Eindhoven, The Netherlands; Philips Research Laboratories August 31, 1966.
308. VOLPE, R. W. "D-C Electric Drive for Off-Highway Vehicles." Society of Automotive Engineers. Paper No. 660199, Mississippi Valley Section Meeting, Nov. 19, 1965. 6 p.
309. WAWRZINICK, et al. "Arrangement for Improving the Operation of Internal Combustion Engines." U.S. Patent No. 3,236,344. February 22, 1966.
310. WEAVER, ROBERT D. "Secondary Lithium/Chlorine Batteries." Proceedings of the 19th Annual Power Sources Conference Fort Monmouth, New Jersey, May 18-20, 1965. pp. 113-115.
311. WIEDHUNER, D. D. "Military Potential of the Small Gas Turbine." American Society of Mechanical Engineers. Paper No. 66-GT-91, Gas Turbine Conference and Products Show, Zurich, Switzerland, March 13-17, 1966. 6 p.
312. WEINBERG, A. M. "Can Technology Replace Coal Engineering." *Bulletin of the Atomic Scientists*, Vol. XII, No. 10, December 1966.
313. WELSH, HARVEY W. "Future Trends in Energy Conversion Systems." Society of Automotive Engineers. Paper No. 660603. Farm, Construction and Industrial Machinery Meeting, Milwaukee, Wisconsin, September 12-15, 1966. 32 p.
314. WERTH, J. "Electric Vehicular Power." American Institute of Aeronautics and Astronautics. Paper No. 66-977, Third Annual Meeting, Boston, Mass., Nov. 29-Dec. 2, 1966. 11 p.
315. WILBUR SMITH and ASSOCIATES. "Future Highways and Urban Growth." New Haven, Conn., 1966. 376 p.
316. WILBUR SMITH and ASSOCIATES. "Transportation and Parking for Tomorrow's Cities." New Haven, Conn., 1966. 393 p.
317. WILCOX, H. A. "Electrical Vehicle Research." Symposium on Power Systems for Electric Vehicles, Columbia University, New York, April 6-8, 1967.
318. WILCOX, HOWARD A. "Present Status of Electric Vehicle Research and Development in General Motors." National Electric Automobile Symposium, San Jose, Calif., Feb. 24-25, 1967. 17 p.
319. WILLIAMS ENGINE CO., INC. "Williams Steam Car." Ambler, Pa., 1967.
320. WILLIAMS, K. R. and B. M. THOMAS. "Fuel Cells As a Source of Power in Locomotives." Institute of Mechanical Engineers. *Proceedings*, Vol. 181, Part 3G, 1966-67.
321. WINTERS, C. E. and W. L. MORGAN. "The Hydrogen-Oxygen Thin Electrode Fuel Cell Module." Society of Automotive Engineers. Paper No. 670182, Automotive Engineering Congress and Exposition, Detroit, Mich., Jan. 9-13, 1967. 6 p.
322. WINTRINGHAM, JOHN S. "Potential Powerplants for Passenger Cars." *Automotive Industries*, 124:55-57, 88, Apr. 15, 1961.
323. WOLOZIN, HAROLD, (ed.) "The Economics of Air Pollution." New York; W. W. Norton & Co., Inc., 1966. 318 p.
324. WORLD HEALTH ORGANIZATION. "Air Pollution." Geneva; World Health Organization, Monograph Series No. 46, 1961. 442 p.
325. WYCZALFK, FLOYD A.; DANIEL L. FRANK, and GENE E. SMITH. "A Vehicle Fuel Cell System." Society of Automotive Engineers. Paper No. 670181, Automotive Engineering Congress and Exposition, Detroit, Michigan, Jan. 9-13, 1967. 17 p.
326. ZAROMB, S. "Aluminum Fuel Cell for Electric Vehicles." Symposium on Power Systems for Electrical Vehicles, Columbia University, New York, April 6-8, 1967.
327. ZURICH, C. J. "The Demand for Transportation Services in a Growing Economy." 42nd Annual Meeting of the Highway Research Board, Jan. 1963. (Also available as RAND Corporation paper P-2682).
328. ZWICK, C. J. "The Demand for Transportation Services in a Growing Economy." 42nd Annual Meeting of the Highway Research Board, January 1963. (Also available as The RAND Corporation Publication No. P-2682.)